ELEMENTARY PRINCIPLES OF PLANT BREEDING

Elementary Principles of PLANT BREEDING

Second Edition

H. K. Chaudhari
Lecturer in Agricultural Botany
University of Udaipur
Udaipur



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PREFACE TO THE FIRST EDITION

The preface is that part of the book which is placed first, written last and read least

—Alfred Lotka

Plant Breeding is the applied branch of botany being taught in B.Sc. (Ag) classes in all the Indian universities. The present book entitled 'Elementary Principles of Plant Breeding' has been written primarily to cover up the syllabi set for B Sc. (Ag) plant breeding course in various agricultural institutions of India It deals with the basic concepts underlying the principles of plant breeding. No doubt, there are some books on the subject but I feel that they are very costly, voluminous, too advanced and beyond the reach and comprehension of an average Indian student of undergraduate classes. In the present text, which is although elementary, an attempt has been made to clear up all the concepts of plant improvement in such a way as to meet the primary need of beginners so that their interest can be promoted in the subject. As a student and later as a college teacher I have constantly experienced the difficulties caused by the absence of any book on the subject suitable for undergraduate students. This situation inspired and initiated me to write the present book which is being put forth here as a remedy for the difficulties which Indian students of agricultural education encounter.

The outline, contents and subject matter of this book has been represented and geared up according to the nitches and needs of average Indian student so that he/she can take interest in going through it to meet his/her ends. In all, the book comprises 12 chapters, each of which relates to the particular topic of plant breeding course The topic of each chapter in turn has been dealt under headings and sub-headings so that students can easily understand and absorb the subject matter Every effort has been made in each chapter to make the matter impressive and easily understandable with the help of photos, diagrams, tables and examples Since economic factor was an important judging factor, only such photos and figures have been reproduced which were felt essential to deal with the subject matter

At the end of each chapter a series of questions have been given covering entire topic to help the learner to check his understanding and grasping capacity.

Few references have been listed at the end of each chapter to guide the students for detailed discussion into the particular portion of the topic.

The glossary of plant breeding terms has been provided at the end of the book to clarify the definitions, differences and application of terms used in the text. This will be very useful to a student encountering plant breeding for the first time.

The special features of the book are:

(1) It is the first book of its kind for B. Sc. (Ag.) students in India.

(2) Going through its first chapter even a layman can understand, what is plant breeding ?

(3) It has been written in simple language systematically so as to stimulate the interest of the beginners in the subject.

(4) For the first time, Indian workers of this particular field with their works have been pictured in this book.

(5) It can serve as a textbook for B. Sc. (Ag.) students and a help book for M. Sc (Ag) and M. Sc. students of Plant Breeding, Agronomy, Horticulture, and Botany.

A book of this type can rarely lay claim to originality as it is nothing but a compilation work done in a manner suitable for the beginners Being from a peasant's class I have a love for labour and this compilation is the labour of that inherited love. Thus, with this compilation I have succeeded in my purpose to serve the students' community. I would now leave the question of usefulness and success of this venture to my readers, teachers and students who, I trust, will show their indulgence and appreciation for the humble effort made by me.

I shall be highly thankful to the readers for pointing out the errors and omissions which in spite of all care might have crept in.

All the suggestions for further improvement of this book will be highly appreciated and accepted to incorporate in the next edition.

May, 1966

H K. CHAUDHARI
Department of Ag Botany
University of Udaipur, UDAIPUR

PREFACE TO THE SECOND EDITION

Many additions, alterations and corrections have been made in the original text, tables, figures, and photos to provide more and better information on the subject Appendix is entirely a new feature to this edition Efforts have also been made to include the latest varieties produced by the different breeding methods.

The author is highly regretful for not providing the readers with second edition in due time on account of overseas presence

June, 1971

Department of Agronomy,
New Mexico State University,
Las Cruces, New Mexico,
U. S. A.

H K CHAUDHARI

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H K CHAUDHARI

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CHAPTER I

NATURE AND SCOPE OF PLANT BREEDING

Plant breeding is the applied branch of botany and deals with the improvement of agricultural crops. This branch of agricultural sciences has contributed maximum to the increase in food production all over the world and, therefore, it is now-a-days assuming ever increasing importance in the amelioration of agriculture in every country.

1.1 Definition

Plant breeding as a science is, however, of recent origin. None has yet given its definition as such, but by going through the matter dealt in this, it can be defined as follows.

Plant breeding means the improvement in the heredity of crops and production of new crop varieties which are far better than original types in all aspects.

Thus plant breeding is the art and science of changing and improving the heredity of plants.

1.2 Aims & Objectives

Main object of plant breeding is to produce new crop varieties superior to existing types in all characters. The detailed objects of improvement vary with different crops However, some objects practically common in most of the crops are given below :

(i) **Higher yield** of grain, fodder, fibre, oil and other plant products.

(ii) **Better quality** with regard to shape, size, colour, nutrition, taste, malting, milling, baking, keeping, cooking, etc. in food grains, vegetables, fruits and flowers. Special quality in produce like higher sugar content in sugarcane; stronger, longer and fine fibre in cotton, more protein content in pulses, and appealing flavour in apples.

(iii) **Resistance** to diseases, insects and pests, frost, flood, drought, wind storms, shattering, lodging and alkaline and saline conditions of soil.

(iv) **Change in duration**, specially earliness or lateness in maturity as needed.

(v) **Change in growth habits** such as dwarfness, few branching and less tillering so as to prevent the crop plants from being blown down, or tallness, profuse branching and more tillering so as to increase the straw for fodder

(vi) Winter hardiness.

(vii) Short and stiff straw to prevent lodging.

(viii) Response to heavy manuring.

(ix) Easier thrashability.

(x) Awned or awnless ears

(xi) Adaptability to wide regions.

(xii) Suitability to machine harvesting in mechanized areas, etc.

These improvements are inherited and, therefore, are more lasting. Thus one can imagine as to how great importance of plant breeding is in crop improvement by synthesizing such varieties which possess all the desirable characters.

1.3 Nature

Art or Science · Plant breeding is as old as agriculture and it was first practised when man learnt to select better plants. In earlier days the nature of plant breeding as an art and as a science was much disputed. The earlier plant breeders relied largely on their skill and judgement in selecting the superior types of plants since at that time scientific knowledge available to-day was not there. The methods used by them, indeed they could not be called methods, were often laborious, costly and time-consuming, and yielded results after long periods of trial and error. Even then, they had achieved considerable success and contributed much to the course of development of many cultivated plants which was entirely due to the accommodating nature of material For them plant breeding was largely an art.

As the knowledge in genetics and other related plant sciences progressed, plant breeding became less of an art and more of a science. The scientists like Lamarck (1744-1829), Darwin (1809-1882), Mendel (1822-1884), Weismann (1834-1914),

Johannsen (1857-1927), Hugo de Vries (1848-1935), Nilsson-Ehle (1908) and Vavilov (1887-1942), added a lot to the knowledge of these sciences and they discovered biological principles underlying the science of plant breeding. Specially the discovery of Mendel's work in 1900 simultaneously by De Vries in Holland, Correns in Germany, Tschermak in Austria and Bateson in England added the laws of inheritance to this science and gave more complexity and exactness to it. By this knowledge of inheritance of characters, it became possible to control the heredity of plants and to create new types of plants more or less at will. On account of scientific nature of plant breeding, there have been tremendous achievements in crop improvement within the short period of 20th century.



Fig. 1

Jean Baptiste Lamarck (1744-1829), a French biologist who formulated the *Theory of inheritance of acquired characters* now known as *Lamarckism*

The modern plant breeding is, therefore, considered as a science based upon a thorough understanding and use of genetical principles Without this precise knowledge and background, the modern plant breeder cannot solve the vast range of problems, and he would be like "a village blacksmith trying to build a modern automobile only with the help of crude tools of blacksmith trade"

Even to-day there are those who believe that art is all that is needed for successful plant breeding, relying perhaps more on luck and intuition than on anything else. But art which is needed in this science is only in the technique of hybridization which too is based on scientific reasons and without the knowledge of genetics this technique of hybridization is not going to pay anything in plant breeding.



Fig. 2

Charles Darwin (1809-1882), an English biologist who gave the concept of *Natural Selection* with the statement *struggle for existence* and *Survival of fittest*

Relation with other plant sciences : The development of plant breeding as a special field of study has been associated with and dependent upon the growth of other plant sciences. It, as an applied science, can be carried out efficiently only through the application of principles of these sciences, prominent among which are :

(1) Genetics
(2) Cytology
(3) Biometry
(4) Taxonomy
(5) Plant physiology
(6) Plant pathology and entomology
(7) Floral morphology
(8) Bacteriology, etc.

Genetics : Genetics deals with the inheritance of characters and laws of heredity while the plant breeding makes use of these laws and combines the different desirable characters together into one variety

Cytology . It deals with the cell and its contents, i.e., chromosomes, nucleolus, etc. In plant breeding the knowledge of these is very essential. Firstly, the cell, in addition to being the vital unit of biological organisation, is also the physical bridge between the generations. Secondly, the karyomorphological studies, i.e., the study of chromosomes and their morphology, are essential for hybridization work Genetics without cytology is, therefore, just like a cell without nucleus. In plant improvement we are concerned with genetics, hybridization and generations. Thus the knowledge of cytology is very much needed in plant breeding.

Biometry It is the statistics applicable to biological data. In plant breeding, for critical comparison of newly produced varieties with local ones, field trials are needed. Data are obtained from these trials, presented, analysed and interpreted with the help of biometrical devices

Taxonomy : In hybridization different types of crosses, i.e., intergeneric, interspecific and intraspecific are made which can be accomplished successfully only if one is quite well versed with taxonomical knowledge. Secondly, in plant breeding improvements, the desired characters are incorporated into a variety. For

this, the presence of desired characters is traced out by studying all the species of that crop, which requires a sound knowledge of taxonomy.

Plant physiology: Plant physiology deals with all the vital processes going on inside the plant body and effects of environmental factors on them. By having their knowledge, in plant breeding the varieties resistant to heat, cold, drought, etc. are produced.



Fig. 3
Gregor Mendel (1822-1884), an Austrian monk famous for his *Laws of inheritance* and is known as *Father of genetics*

Plant pathology and entomology: The diseases and insect pests are of great importance in crop production because they are main enemies of plants. In plant pathology and entomology, besides studying the diseases and insect pests, the host and parasite relationships are studied. This knowledge of host and parasite relationship is utilized in plant breeding for production of resistant varieties to these enemies.

Floral morphology: In plant breeding crosses are made for hybridization. For successful crossing, a familiarity with structure, behaviour and mechanism of opening and closing of flower is essential.

Bacteriology: In leguminoceae family, recent work suggests that plant genotype and rhizobial strain specialization may be related, thus bacteriology becomes more pertinent.



Fig. 4
Nilsson-Ehle, Swedish Plant Breeder who profounded the *Multiple gene hypothesis* to explain the genetic mechanism of quantitative inheritance

Agricultural engineering: Increased use of machinery in crop production requires evaluation of varieties as to know their adaptability for machine culture and handling.

These sciences are the tools with which plant breeder works and uses his knowledge of these sciences to create the new crop varieties, just as the engineer uses his knowledge of mathematics,

physics, or chemistry to construct a new bridge or modern skyscraper.

It is obvious that a plant breeder can not be a specialist in all these sciences. In the actual breeding work, he is not working exclusively in any one of them. His work is to apply the whole of his knowledge and experience towards the development of superior varieties If any additional knowledge is required, he may contact respective specialists or may work with a team of different specialists each contributing to the work in his field and the plant breeder co-ordinating the whole to the end so that a superior variety may be developed.

1.4 Economic Importance

Food problem and plant breeding : One of the gravest problems, facing not only India but whole of the world to-day, is that of feeding ever increasing population Salvation of this problem lies in keeping the balance between the population increase and supply of food. To restore this balance we have to

(i) check the population increase and

(ii) tap the new sources of food supply.

In agriculture, though we are mainly concerned with the second one, even then it is essential to deal with the former in brief for tracing out the comparative importance of the latter.

In the past the major scourges which kept the human population under control were wars, diseases and lesser care of offsprings Now wars have become less frequent though more frightful. Diseases are being controlled by modern medicines particularly by antibiotics and sanitation schemes such as Malaria Eradication Programmes and others. Offsprings are getting an increasing amount of care so that the number of survivals to adulthood becomes greater. On account of medicines and more care a child born today has at least two to three times better chances of living full span of life than was possible in the past. This has largely



Fig 5
Nikolai Ivanovich Vavilov (1887-1942), a Russian Plant Breeder famous for his classical work *The centers of cultivated plants* published in 1926.

contributed to population increase in many countries

Now-a-days there are voluntary population control measures such as family planning and birth control. These measures are still in infancy. But unless these are applied, imbalance between the number of pepole to be fed and supply of food available is likely to become more serious. Being in infancy these measures have not yet contributed mucn towards population control. The only way to solve this problem is, therefore, to tap the new sources of food supply which are ·

(i) Photosynthetic factories
(ii) Microbial food
(iii) More production by improving agriculture through the application of
  (a) fertilizers,
  (b) disease, insect pests, and weed control by chemicals,
  (c) cultural practices, and
  (d) plant breeding

Photosynthetic factories and microbial food have not yet been developed and, therefore food production can be increased only through the improvement of agriculture.

Plant breeding as a far better method of food-problem salvation Improvements by fertilizers, disease and insect pests control, and cultural practices have several limitations in practical utility such as

(1) They are one-aimed improvements in the sense that only the yield can be increased upto some extent but other characters cannot be improved
(2) By them the inherited qualities and characters can not be controlled, i e, the achievements obtained by them are not lasting
(3) The present demand for fertilizers and chemicals can not be fulfilled by their existing production
(4) These methods are laborious, costly and time consuming.
(5) They are not quite satisfactory in eradication of parasites thoroughly.
(6) They are totally helpless to control some diseases like virus and nematodes

Under these circumstances the best method to control all these maladies, therefore, seems to be the improvements by plant breeding.

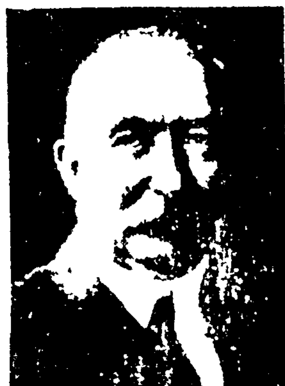


Fig. 6

Sir Albert Howard, a British scientist, who for the first time started plant breeding work in India and is considered pioneer in crop improvement *(By courtesy of Dr. Swaminathan)*

Plant breeding utilizes all the contributions made by different sciences and welds them into a new variety possessing as many desirable characters as possible. The plant breeder is, therefore, the leader of team in agriculture. He is the only person in agriculture who can advise the farmer on how to improve his crops in all respects. The farmers give them practical shape. Hence the plant breeders are practical humanitarians ever striving to improve the welfare of man and animal and to abolish the poverty, scarcity, famine and misery, and the plant breeding is the only sure and the least expensive method of food-problem salvation as compared to any other measure of agriculture.

1 5 History and Achievements

The United States, which is the world's largest producer of wheat, cotton, maize and citrus fruits, could make progress and vast strides in crop production by breeding improved types of plants and using hybrid vigour. About 85% of the acreage under corn in U S.A. is now sown to hybrid corns Hybrid maize has increased crop production by 20-25% and has fetched millions of dollars of additional income to American farmers.

In the field of horticulture, development of wilt resistant Marglobe tomato has helped to save the Florida Shipping Industry from ruin. Rutgers and Sioux tomatoes have gained wide reputation for their performance in India. Cantaloupes resistant to powdery mildew developed by using Indian muskmelons have helped to tide over a crisis in their production in California.

Similarly in Soviet Russia according to Lysenko, over 150 varieties of fruit plants comprising apples, pears, plum and peaches, have been bred for various tracts to overcome severe winter, frost and disease troubles.

(2) Purification of unimproved or mixed varieties.

(3) Maintaining the purity of a variety where supply of seed is not properly organised. The selection of ears in *bajra*, maize, wheat sorghum, and in other crops by farmers accomplishes the same purpose.

Application of mass selection to already improved or pure strains rarely leads to any radical improvement and, therefore, it must not be used in pure varieties.

ADVANTAGES

(1) It is the simplest, easiest and quickest method of crop improvement because of the following facts :

(a) No testing of produced variety is required.

(b) No control of pollination is done for production of the variety.

(c) It is more of an art than a science.

(2) It is only the method for improving the wild or local varieties to meet the immediate needs of farmers. Secondly, it serves as the first step in their improvement. After application of mass selection other methods of crop improvement are exercised in them for further achievements.

LIMITATIONS

(1) Improvements by mass selection are short-lived and the anticipated results are not obtained because of the following facts :

(a) Variety produced is heterozygous, i.e., mixture of different genotypes.

(b) There is no control over the pollination which causes still greater heterozygosity.

On account of these reasons the characters segregate in each generation causing quick deterioration of the varieties. To overcome this limitation the mass selection is repeated in every season, specially in cross-pollinated crops. Thus, continuous vigilance has to be exercised as otherwise the strain will lose their efficiency very quickly.

(2) Mass selection is not good for increasing the yield because,

(a) attention is paid only to maternal characters during

selection and genes contributed by male parent are not considered at all,

(b) yield fluctuates greatly with environmental variations and the phenotypic and environmental effects can not be separated out,

(c) it is also not possible to distinguish between plants phenotypically superior owing to the environment from those superior owing to heredity, and

(d) uncontrolled pollination may cause the selected plants to be pollinated by both superior and inferior pollens.

(3) It is often not applicable to self-pollinated crops because due to less amount of heterozygosity the limits of selection are achieved within short time in them.

ACHIEVEMENTS

In spite of these limitations, mass selection has been the most common method of crop improvement among farmers. All the cultivated crops and their local strains are the results of mass selection operating in the nature automatically. Although most of the local varieties of crops have been developed by mass selection, unfortunately no clear-cut records are available in most cases to indicate whether mass selection or pure-line selection was used. However, few examples are cited here. A good success was achieved by this method in the early days of *Gossypium arboreum* breeding in Madras. The first commercial types of *hirsutum* cotton in India such as *Dharwar American, Dodahatti local, Cambodias etc.*, are the products of unconscious mass selection in the introduced material. The varieties of groundnut such as TMV.1 (A. H. 25) and TMV.2 (A.H.32) of Madras; Groundnut No. 1, Gangapuri and A. H. 14 of Punjab; and A. K. 10 and A. K. 8-11 of M. P. have been developed by mass selection. The varieties T. 13, T. 19, T. 41, Jaunpur, Tinpakhia, Darjeeling White Round, Darjeeling White Flat, Darjeeling Yellow Round, Bassi selected, Udaipur selected, etc., of maize, T. 5 (Pb.), T. 55 (Pb.), S 530 (Pb.), Pusa Moti (IARI), R. S. K. (Raj.) and R. S. J. (Raj) of *bajra*; R. S. 1. (Raj) and T. 22 (U. P.) of sorghum; K. 122 (U. P.) of patato and Br. S. G. of *sarson* are also the results of this

selection. Similarly in other crops most of the indigenous varieties are the products of mass selection.

CONCLUSION

Mass selection is the simplest method of breeding crops and has shown more overall effects in cross-pollinated crops than all breeding methods combined. Even today, it is an important part of the crop improvement as it goes hand in hand with hybridization programme. It is also known as the "German method or German method of broad breeding" because once it was used widely in Germany for improving the sugarbeets and small grains such as rye and wheat.

Questions

1. Define "mass selection" and discuss the criteria of selecting plants or ears in this method.
2. In which type of crops the mass selection is used and why ?
3. Would mass selection give better results in self-pollinated crop such as wheat or in a cross-pollinated crop such as *bajra* ? Explain.
4. Can mass selection be adopted in an already improved variety of a cross-pollinated crop ? If not in what type of plant material it must be adopted in the cross-pollinated crops ?
5. How much time is taken by mass selection for production of a new variety and what steps are involved ?
6. Differentiate between Hallet's and Rimpau's method of mass selection.
7. Cite a few examples of varieties produced by mass selection in maize, cotton and *bajra*.
8. How the mass selected varieties, as such, are maintained year after year ?
9. Discuss the merits and demerits of mass selection.
10. "Mass selection is more of an art than a science" explain.
11. How can you say that farmers indeed practise mass selection every year in their crops unknowingly ?
12. Define the terms *elite*, *en masse* & compartmental selection.

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CHAPTER V

PURE-LINE AND PURE-LINE SELECTION

The term *pure-line* was suggested for the first time by W. L. Johannsen of Denmark in 1903 while working with Princess variety of beans *[Phaseolus Vulgaris]* and he gave its definition as "The descendants of a single self-fertilized organism of homogeneous factorial composition". Later on, many authors defined it and some of the definitions are given below :

Hayes, Immer and **Smith** (1955) define pure-line as "A strain of an organism that is comparatively pure genetically (homozygous) because of continued inbreeding or through other means".

Sinnot, Dunn and **Dobzhansky** (1950) are of the opinion that the progeny of a single individual obtained by selfing is called a pure-line.

Poehlman (1959) defines pure-line as "A strain in which all members have descended by self-fertilization from a single homozygous indivi-daul"



Fig 16

Wilhelm L. Johannsen (1857-1927) a Danish geneticist who gave the concept of "*pure-line selection*" for the first time and coined the terms '*pure-line, Genotype & Phenotype*'.

Darlington and **Mather** (1952)—A pure-line is an inbred homogenic strain.

Jones says that a pure-line comprises the descendants of one or more individuals of like germinal constitution that have undergone no germinal change.

All these definitions carry the same meaning and a simpler definition with the same sense may be given as follows :

A pure-line is a strain made up of the progeny of a single self-fertilized homozygous individual.

or

Pure-line is a group of plants all obtained from a single self-fertilized homozygous plant.

CHARACTERS OF A PURE-LINE

Two main characteristic of a pure-line as being reflected by its definition, are ;

1. **Progeny of a single self-fertilized plant**—A pure-line is composed of many plants all descended from a single self-fertilized plant. It is also propagated by selfing its individuals or crossing them with genetically indentical plants.

2. **Genetically uniform**—The plants of a pure-line are homozygous and, therefore, they all are uniform genetically and phenotypically and pure for all the characters except some minor phenotypical differences which arise due to variations in the environmental conditions. They remain pure until mutation or hybridization intervenes. The once isolated pure-line, therefore, remains constant until and unless mechanical mixing, natural cross-pollination and changes in its genotype occur.

PRODUCTION OF PURE-LINES

1. **In self-pollinated crops**—The self-pollinated crops are generally homozygous and, therefore, pure-lines occur in them naturally. They are separated out easily by growing the progeny of selected plants separately to accomplish the purpose of pure-line production.

2. **In cross-pollinated crops**—The plants of cross-pollinated crops are always heterozygous and subjected to self-fertilization for a number of consecutive generations to obtain the pure-lines The repeated self-fertilization in successive generations results in the rapid elimination of heterozygosity and making the population homozygous. Such self-fertilizations in the cross-pollinated crop result in decline in vigour and productiveness This decline is more rapid in the first few generations and produce many defective and abnormal individuals like albino. dwarf plants, etc., but after seven or eight generations the decline ceases and the

survivals are pure-lines. Such obtained pure-lines are known as *inbreds* in cross-pollinated crops.

IMPORTANCE OF PURE-LINES

1. **Used for production of new varieties**—The pure-lines are sorted out from the mixed population of self-fertilized crops by the pure-line selection and those found superior are released as the improved varieties.

2. **Used for detection of variations**—Pure-lines are important both in scientific experiment and agricultural practices. The effects of environmental factors can be measured by growing the members of a pure-line under different conditions. In laboratory animals such as rats, guinea pigs, etc., the existence of inbreds is useful for measuring the effects of nutrition, disease resistance, etc.

PURE-LINE SELECTION

The method of pure-line selection has been developed from the classical work of Johannsen on pure-lines and is commonly used to improve the self-pollinated crops. This consists in selecting a large number of single plants or heads, growing their progeny separately in the field trials, and saving the single most valuable progeny as a new variety. Pure-line selection is thus the process of separation of the crop population into genetically distinct groups, each uniform within itself. It can be defined as follows :

The process of isolating a desirable homozygous individual from the mixed population and multiplying the same without contamination to release as a new variety is known as pure-line selection.

Pure-line selection has many synonyms as given blow :

1. **Individual plant selection,** because the individual plant is the basis of pure-line selection.

2. **Head-to-row selection,** because in the thickly planted and profusely tillering crops such as wheat, oat and barley where individual plant can not be selected, head is selected and sown in a row separately.

3. **Progeny selection,** because selection in further gener-

ations is made on the basis of performance of the progeny of individual plants.

4. **Pedigree selection**—At the Swedish Seed Station of Svalof it is known as Pedigree system or Pedigree selection.

5. **Single line selection,** because the single plants are selected and their progenies are maintained separately.

6. **Inbred selection,** because inbreds or pure-lines are produced to constitute the varieties by pure-line selection.

FIELD TECHNIQUE

Generally a period of eleven years is required to produce a variety by pure-line selection in cross-pollinated crops and the different steps involved in each year are outlined below :

First year—50 to 1,000 plants or heads are selected from the mixed population of ryots' fields at the the time of harvest. The produce from individual plants is picked separately and numbered.

Source of selection . The plants or heads may be selected either from ryots' fields or from the crop grown at research station from the bulk sample of seeds collected from different representative villages in the previous year. But it is always advisable to make selection from the ryots' fields so that the trouble of collecting the samples from villages and sowing the same at research station can be avoided and the time taken in collecting the samples is saved.

Unit of selection : The individual plant is generally made the unit of selection but in thickly planted crops, where individual plants can not be separated apart, the single heads from the different plants may be made the unit of selection.

Characters to be observed: The characters of the whole plant or head such as appearance, height, size, colour; resistance to diseases, insects, drought, frost and lodging; maturity, tillering, awned or awnlessears, yield, etc., are noted at the time of selecting the individual plants. If pure-line selection is with any particular object, such as disease resistance, colour of grain, maturity, etc., the selection in the local material is made on that basis so that the primary characteristics are not lost. The yield may be considered but it must not be made the only character as the basis of

selection, since it is subjected to a great deal of environmental variation. Many important economic characters such as length, size and resistance are not subject to large developmental variations and they may be made the basis of selection. It must be remembered that the characters of the whole plant are more important than those of any particular part and the more uniform the plant in all its parts the greater is the likelihood that they will prove better for selection.

Number of plants to be selected. The total number of initial selection varies from 50 to 1,000 plants or heads, but it depends on the crop and the amount of land and funds available for subsequent testing.

Second year—25 to 50 seeds of each plant are grown in an individual row for observational purposes. Every tenth row is seeded to some standard variety or local bulk with which they are to be compared. Apparently defective rows are eliminated promptly. The disease resistance can be judged by the artificial infection and the rows or plants susceptible to diseases can be easily eliminated. In second year, therefore, all the plant rows that appear of undesirable types are discarded and the superior, i.e., the desired progenies of rows are harvested. The seeds from plants within each row are composited together and this composite produce of each row becomes an experimental strain.

Third year—The **preliminary yield trials** are conducted in which the same process of second year is repeated and the more undesirable rows are discarded. The only difference is this that the each strain of second year is sown into 3 to 4 rows instead of in one row as in second year. All the undesirable strains and the plants within the strains are eliminated. The desired plants of the strains are harvested and the seeds of each strain are composited separately.

Fourth to Sixth year—The **main yield trials are carried out** in which the seeds of each strain are sown usually in seven-rows-plots replicated five or six times with one standard strain or local strain plot as control for comparison. The superior strains are selected and kept, and the others are discarded Besides comparing yields, analyses for other economic characters are also

conducted on the plot-wise data collected The yield trials are similarly conducted upto sixth year. In the sixth year, one or two or at the most three strains, which show consistent superior performance over the standard strain in respect of yield and quality, are ultimately selected as improved strains.

Seventh year—The seeds of these strains are multiplied.

Eighth to Tenth year—The seed of each superior strain is sent to progressive farmers in different regions for **district yield trials on ryots' fields** There the comparative yield trials are conducted for three consecutive years and their performance is reported to the plant breeder in the tenth year The breeder, on the basis of comparative performance, selects one or two strains and gives names to them They are multiplied and distributed to farmers for general cultivation in subsequent years

The number of years indicated is arbitrarily suggested but may vary depending upon the crop and the speed with which improvement in desired characters is achieved.

VARIETIES

The varieties developed by pure-line selection are the progenies of single self-pollinated plants and, therefore, they are homozygous, uniform and lasting Genetically they are pure-lines.

PRECAUTIONS

Three main precautions to be kept in mind during the pure-line selection are :

(1) Mechanical mixture of seeds from other varieties of the same crop or other crops should be avoided. The main source of mechanical mixture is seed-cleaning equipments or other equipments which have common use in many crops

(2) Natural cross-pollination In self-pollinated crops, in which the pure-line selection is generally practised, there is very little chance of cross-pollination but even then the sources of cross-pollination should be avoided The first source of cross-pollination is admixture of a variety and the second source is from sowing of two varieties of the same crop in the adjacent fields or plots

(3) Mutation . Off type plants must be removed every

year so that the spontaneously created mutations may not become the source of variation in the improved strains.

USES

Pure-line selection is usually exercised in the mixed population of naturally self-pollinated crops where the population is a mixture of different homozygous plants, i.e., heterogenous. As a result of selection in such mixed population the several homozygous forms, i.e., pure-lines are separated apart which are either used in further breeding work or released as new improved varieties directly. The purposes of pure-line selection can, therefore, be as follows :

(1) Pure-lines in a crop may be used either as new improved varieties as in self-pollinated crops or as the parents in hybridization programme as in cross-pollinated crops.

(2) The farmers' mixed varieties of self-pollinated crops are easily separated apart, purified or sorted out into different strains each uniform within itself in respect of yield, stand, maturity, disease and insect resistance, milling, etc.

This method cannot be employed in the already improved varieties or pure-lines, because in them no variation is found which can be exploited by pure-line selection and, therefore, selection in them leads into no improvement.

ADVANTAGES

(1) It is the only method to improve the local varieties of self-pollinated crops.

(2) It is easier than the hybridization method of crop improvement in self-pollinated plants, because in this no emasculation and crossing are involved.

(3) The varieties produced by pure-line selection are extremely uniform in appearance and performance and, therefore, are more attractive.

(4) It is used both in self-and cross-pollinated crops for production of pure-lines and inbreds.

DISADVANTAGES

(1) Pure-line selection, for the production of new varieties, is used only in self-pollinated crops and not in cross-pollinated crops because of the following reasons:

(a) Extra attention and labour are to be paid for self-pollination in cross-pollinated crops.

(b) It results in low yielding, albino and dwarf plants in them

(c) If at all a variety is released by this method in cross-pollinated crops, the farmers cannot maintain it because they do not know how to control the pollination and ultimately the variety is lost.

(2) **There is no possibility of introducing new characteristics not originally found in the population, i.e., no new genotypes are created by pure-line selection.** Improvement by this method is, therefore, limited to the isolation of the best genotypes already present in the mixed population and it reaches its extreme limits as soon as the already occurring variation is exhausted in whole of the local bulk.

(3) The varieties produced by pure-line selection are homozygous and, therefore, are not adapted to large areas under varying conditions.

ACHIEVEMENTS

The pure-line selection in naturally mixed population of self-pollinated crops has resulted in the isolation of many useful and improved strains as given below :

Wheat *(Triticum aestivum* L.*)* :—N. P. 4, N. P. 6, N. P. 12, 9-D, 8-A, K. 13 and K. 54.

Rice (*Oryza sativa* L.) :—Adt. 1, Adt. 3, Adt. 5, Adt. 10, Co. 4, Co. 6, Co. 10, Co. 14, Mtu. 1, Mtu 3, Mtu. 6, Mtu. 9, Mtu. 13, Ptb. 1, Ptb. 4, Ptb. 7, Ptb. 10, S. P. 1, S. P. 2, etc.

Jowar (*Sorghum* sp.) :—Co. 1, Co. 4, Co 5, A S. 1543, A. S. 1575, A. S. 2095, A. S. 3355, etc.

Cotton (*Gossypium* sp.) :—Co. 2, C. 7, A. 10, 231 R, C. 520.

Barley (*Hordeum vulgare* L.) :—T. 4 (Pb.), T. 5 (Pb.), R. S. 17 (Raj.).

Groundnut (*Arachis hypogaea* L.) :—T. M. V. 3 (A. H. 698), T. M. V. 4 (A. H. 334), H. G. 8, K. T. 18, K. T 23, K. T. 24, K. T. 25, R. S. B. 17 (Raj.).

Linseed (*Linum usitatisimum* L.) :—N. P. 5, N. P. 9, N. P. 12, N. P. 142 and EB. 16 A.

Rai (*Brassica juncea* Coss) :—T. 3, T. 5, T. 9, R T. 11, Laha 101 and L 18.

Yellow *Sarson* (*B. compestris* var. *Sarson* Prain.) :—A. G. H. -A and Y. S Muzaffarnagar.

Tobacco (*Nicotiana tabacum* L.) :—N. P. 28, N. P. 63, T. 23 and T. 59.

Jute (*Corchorus capsularis*) :—D 154.

Jute (*Corchorus olitorius*) :—C. G. (Chinsurah) green.

Cowpea (*Vigna sinensis* Savi.) :—R. S. 1, R. S. 2, R. S 14 (Raj), Gwalior K-3B, Gwalior K-11, Gwalior K-14.

Moong (*Phaseolus aureus* Rexb.) :—*Moong* Khargone No. 1 (Pb.), B 1 (W Bengal), and R. S. 4 (Raj.)

Gram (*Cicer arietinum* L.).—R. S. 10 (Raj.).

Urid (*Phaseolus mungo* L.) :—*Urid* Khargone No. 3 (Pb.).

Arhar (*Cajanus cajan* Milsp.) :—Tuer Khargone No. 2 (Pb.).

Guar (*Cyamopsis tetragonoloba* Taub.) :—Durgapura Safed (Raj.)

CONCLUSION

Table 3 Differences between mass selection and pure-line selection

S. No.	*Mass selection*	*Pure-line selection*
1.	Mass selection is as old as agriculture itself.	Pure-line selection is not so old as is mass selection.
2.	It is followed by farmers every year in their crops unknowingly.	It is never practised by farmers in their crops
3	It is usually practised in cross-pollinated crops.	It is always practised in the self-pollinated crops.
4	A large number of plants are selected.	Comparatively lesser number of plants are selected.
5.	The produce of the selected plants is mixed together and sown as such in the next year.	The produce of the selected plants is kept separate and the progenies of each plant are sown separately in an individual row in the next year.

6.	The testing of the progeny is not carried out.	The progeny as well as the individual plant's performance is tested.
7.	There is no control over the pollination.	The pollination is controlled.
8.	The variety developed by this method is heterozygous and, therefore, is not uniform and attractive in appearance.	The variety produced is homozygous and, therefore, is uniform and attractive in appearance.
9.	The variety produced by this method deteriorates very quickly due to heterozygosity and cross-pollination.	This variety developed is homozygous and is, therefore, more lasting.
10.	To maintain the purity of the developed variety the mass selection is repeated every year in it.	The variety developed is easily maintained without any sort of heed and thus, there is no need to repeat the pure-line selection in it every year.
11.	The variety developed is suited to large areas under varying climatic conditions.	The variety develeped is homozygous and, therefore, is not suited under varying conditions but is adapted to a limited region.
12.	About 8 years time is taken for production of a variety by this method.	About 10 years period is consumed in producing a variety by this method.
13.	It is easier and simpler since no knowledge of genetics and techniques of field designs is required. It is, therefore, said that the mass selection is more of an art than a science	It is more laborious and complex than mass selection because in this the knowledge of pollination and techniques of field designs is required for testing the progeny. It is, therefore, more of a science than an art

Questions

1. Define the term 'pure-line' and describe how it is produced in the crops of different modes of pollination ?
2. Give the genotypical and phenotypical characters of a pure-line.
3. Who coined the term 'pure-line' and in which year ? What is its importance in genetics and plant breeding ? Discuss.
4. Give the definition of 'pure-line selection' and state what are its synonyms ?
5. Describe the field technique of pure-line selection year-wise briefly and mention the precautions to be taken during its operation.
6. What is the effect of selection within a pure-line ? Discuss the reasons with your opinion.
7. In what type of crop material the pure-line selection is used ?
8. Variety R. S. 14 of *moong* was produced by pure-line selection. What genetically it is ? Is it advisable to use pure-line selection in it immediately after its release ? Is there any use of applying pure-line selection in this variety after ten years of its release ? Discuss with reasons.
9. The pure-line selection method of crop improvement produces no new genes in the plant material, then how the improvement is brought in by this method in crops ?
10. What are the features of a variety produced by pure-line selection ?
11. List the advantages and disadvantages of pure-line selection.
12. Make an exhaustive comparison in between the mass selection and pure-line selection.
13. Quote some instances of achievement obtained by pure-line selection in wheat, barley and groundnut.

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CHAPTER VI

CLONE AND CLONAL SELECTION

The crop plants can either be propagated by seeds or by vegetative parts The vegetative propagation is resorted due to lack of seed formation or production of seeds under special conditions, short viability of seeds and wide heterozygosity in plants.

All the commercial varieties of sugarcane, banana and potato are generally *sterile* due to non-flowering habits, meiotic irregularities or other genetic causes and produce no seeds. The *unsuitable climate* in sugarcane and potato, and *cultural practices* in garlic and some ornamental plants also *result in lack of seed formation,* and enforce the use of vegetative parts for their propagation. Sometimes the seeds are formed in sugarcane, but they *loose their viability within a few weeks* on their ripening and, therefore, can not be used for raising the crop in the next year Most of the fruit trees such as mango, orange, apple, etc , and sugarcane show a *wide heterozygosity* and *high degree of polyploidy.* If they are propagated by seeds, there will be great variations in the population resulting in poor production. Being heterozygous, they do not breed true to type and also the purity of race is not maintained. On account of these obstacles, the crops like sugarcane, banana, potato, onion, turnip, etc., are propagated by their vegetative parts in each generation and crop population in them is composed of direct vegetative descendants from different plants. All the vegetative descendants of a single plant are together known as clone and it may be defined as follows:

All the vegetative progenies of a single plant

or

All the progenies of a single plant obtained vegetatively are known as a clone.

Sometimes a clone is also defined as a variety or a group

of plants obtained vegetatively from a single plant, which does not differ in the meaning from the aforementioned definition.

CHARACTERS OF A CLONE

All the plants of a clone are the offsprings of a single plant descended by mitosis through the process of vegetative propagation and possess the following characteristics :

(1) All the members of a clone are identical or there is no variation within a clone—All the individuals of a clone are in fact the pieces of a single plant and, therefore, they are genotypically and phenotypically identical. The cause of this resemblance is their origin and development from the single parent plant by mitotic cell division in which there is no mechanism that permits any change in the daughter cells from the mother cell. The variations in daughter cell occur only during meiosis due to pairing and crossing over of homologous chromosomes, separation of paired chromosomes, and union of gametes from different plants, which do not take place in the clone. The members of a clone are thus identical, i.e., have the same genotype, breed pure to parental types and also have the characteristics of producing genetically uniform progenies. If there is any variation in them that is wholly due to environmental differences When environment is highly uniform, differences between plants will be small and when environment is very variable, they will be large But no matter whether small or large, they are only phenotypical not inherited differences. Genetic variability in a clone arises only due to bud or somatic mutations which are very rare and if at all there, they are of no agronomical importance because of very low frequency of their occurrence. The variation between population of different clones is due to the differences in their genes as well as environment.

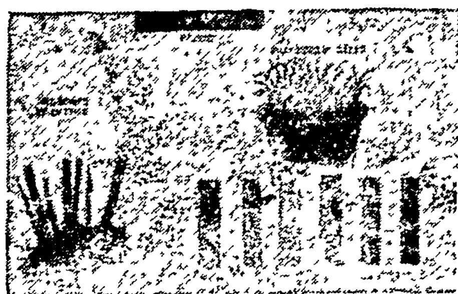


Fig 17

A, note the uniformity among the members of a clone and B, variation among the progenies that arise by seeds (After Chandrasekharan and Parthasarathy)

(2) **All the members of a clone are heterozygous**—The plants of a clone may be all alike but genetically they are heterozygous. The genetical constitution of all these plants depends upon the genotype of parental plant. The parental plant in vegetatively propagated crop is always heterozygous which can be easily exploited and seen from the variations arising among the seedlings raised by seeds of a clone. That is why, the improved fruit trees such as mangoes, potatoes and citrus are not raised by the seeds but by the vegetative parts so that poor yield may not result.

(3) **Clones are stable**—The clones are as stable as pure-lines and no segregation or variation occurs in them in their future generations. Even after many years of cultivation and vegetative propagation, a clone retains its original characters as such. It is mainly due to the fact that many trees evolved many years ago and propagated vegetatively still retain their desirable characters.

(4) A clone is obtained by vegetative propagation from a single plant and is also multiplied vegetatively in future generations.

The clonal population, being alike genotypically and lineal descendants of a single plant, resembles the pure-lines including the identical twins. They differ from them, however, only in two fundamental ways. First, the various plants of a sexually reproduced pure-line are homozygous and genotypically alike except mutation, while the members of a clone, though genotypically alike except mutations, are always heterozygous. Second, the repeated self-fertilizations in a heterozygous plant result in the production of a number of pure-lines while only one clone is produced by repeated vegetative propagation from one heterozygous plant, apart from somatic mutations.

IMPORTANCE OF CLONES

Owing to heterozygosity and sterility in many crops, clones are only the means of perpetuating them. They are also used to produce new varieties in vegetatively propagated plants by clonal selection. Besides this, the clones are very useful tools to preserve the once obtained superiority in plants.

CONCLUSION

Differences among a pure-line, clone and an inbred—All these terms are invariably used in different breeding procedures as pure-line in pure-line selection of self-pollinated crops, clone in clonal selection of vegetatively propagated crops, and inbred in hybridization of cross-pollinated crops. Comparative differences among them have been given in Table 4.

CLONAL SELECTION

Clonal selection is one of the methods for improving the vegetatively propagated crops such as sugarcane, banana, potato, citrus, sweet potato, mango, apple, orange, grapes, litchies, turnip, sugarbeet, some grasses, many ornamental plants and fruit trees. It consists in isolating the best clone or clones from the mixed population and is defined as follows .

Clonal selection is the selection and propagation of the desirable variations between the clones as well as within a clone.

or

Clonal selection is the method of selection of desirable clones from the mixed population of vegetatively propagated crops

FIELD TECHNIQUE

The clones are selected from the mixed population of a crop and the unit of selection differs from crop to crop as listed below :

Stem cutting	—	Sugarcane, sweet-potato, betel vine, pepper, lucerne and some ornamental and hedge plants.
Tubers	—	Potato.
Suckers	—	Banana, pine-apple, aloe, agave, chrysanthemum, etc.
Grafts and buds	—	Fruit trees and flowering plants such as mangoes, citrus, rose, apple, etc.
Bulbs	—	Onion and garlic.
Runners	—	*Doob* grass.
Corms	—	Colocasia and yam.
Layering	—	Flowering plants such as jasmine, rose, etc

Table 4. Differences among a pure-line, clone and an inbred

S. No.	Differences among	Pure-line	Inbred	Clone
1.	**Parents**	Progenies of a **single self-fertilized homozygous plant.**	Progenies of either a **single cross-pollinated heterozygous plant** or two closely related plants.	Progenies of a **single vegetatively propagated heterozygous plant.**
2.	**Production**	Produced **by natural selfing.**	Produced by **artificial selfing** as well as mating of closely related plants.	Obtained by **vegetative propagation.**
3.	**Genetical constitution**	All the plants of a pure-line are identical and **homozygous.**	All the plants of an inbred are **more or less** identical and **homozygous.**	All the members of a clone are identical having same genotype but **heterozygous.**
4.	**Occurrence**	Usually found in **self-pollinated crops.**	May be present both in cross-pollinated crops as well as in animals.	Occurs only in **vegetativaly propagated** crops.
5.	**Importance**	Utilized directly as the **improved variety** as well as the **parent of cross** in hybridization.	Utilized **only** in hybridization as the **parent of cross.**	Utilized directly as the **improved variety** as well as the **parent of cross** while crossing.

Many other vegetative parts such as root-suckers, root-tubers (Dahlia) and bulbils are also made the units of clonal selection.

The healthy units from healthy plants are picked up on the basis of desired phenotypical characters after adequate testing under field conditions. The diseased and poor yielding clones are discarded immediately. The selection within a clone is never effective unless mutation intervenes because of the fact that all the individuals within a clone have the same genotypical constitution. The source of clonal selection is both local varieties as well as introduced crop material.

The selected clones, may be any part of the plant body, are multiplied by the particular method of vegetative propagation as is applicable separately in the different crops. They are then compared with the normal variety. The best performers, from all view points of economic importance, are selected and carried on under comparative trials at different regional stations for three years continuously. The best proved ones are given the names, multiplied, recommended and distributed to the farmers.

Where successful hybridization can be made between the varieties of a clonal population and viable seeds can be obtained, the crosses between best combiners are made. Hybrids thus obtained are studied for desirable characters. The best one is selected, multiplied and compared with standard varieties. If found suitable under trials, it is named, multiplied, recommended and distributed to the farmers.

The time taken in producing a variety by this method depends upon the method of vegetative propagation applicable in the particular crop. The variety produced is stable possessing all the original characters of the parental clone as such.

ADVANTAGES

(1) Varieties are stable and easy to maintain—The varieties produced clonally are as stable as pure-lines and there is no danger of variations resulting from Mendelian segregation. Hence, the fear of deterioration is totally reduced and the varieties retain their characteristics as such even after many years of cultivation unless mutation occurs and produces bud sports, chimaeras and genetic mosaics.

(2) **Hybrid vigour is easily utilized**—If once a plant with hybrid vigour is obtained by hybridization, it can easily be preserved by vegetative propagation in the clonal crops and, therefore, there are great possibilities of its utilization in each generation. Further, on account of clonal propagation, there arises no problem of hybrid seed production every year as is prevalent in the case of hybrid maize.

(3) **Only method to improve the clonal crops**—Clonal selection is only the way to improve the vegetatively propagated crops. Sometimes hybridization is also practised in some of them but ultimately selection among the hybrids is made by clonal selection.

LIMITATIONS

(1) **Only applicable to vegetatively propagated crops**—There are many crops, for example, wheat, barley, cotton, *bajra*, *moth*, *guar*, etc., which are multiplied always by seeds and, therefore, in them no improvement can be obtained by clonal selection.

(2) **Creates no new variation**—The progress of clonal selection is limited to the isolation of best genotypes already present in the population until and unless it is followed by hybridization. Hence, indeed, there are very little chances to improve the heredity of plants by this selection.

ACHIEVEMENTS

Two clonal selections, *Kufri Red* from Darjeeling Red Round and *Kufri Safed* from Phulwa have been isolated in potato and are already under commercial cultivation. Further, the clone Nos. 2, 3, 8 and 23 in Darjeeling Red Round and 3, 6 and 29 in Phulwa are under the different stages of recommendation. Many varieties such as *K.O. 11*, *K.O. 22*, *Mundapa Pedda Neelum* in mango, *Bombay Green* from Dwarf Cavendish, *Batheesas* and *Pidi Monthan* from Monthan, *High Gate* from Gross Michel in banana, *Yuvraj Blood Red* in sweet orange, etc are also considered bud mutants selected by clonal selection. Similarly in citrus, grapes and other vegetatively multiplied plants, all the old commercial strains are the results of clonal selection.

CONCLUSION

Clonal selection offers an opportunity to exploit desirable mutations occurring in somatic parts of plants and also helps to eliminate unproductive and undesirable types which occur from time to time in commercial varieties of vegetatively propagated crops.

Questions

1. Why the vegetative propagation is adopted in certain crops and not in others ?
2. In sugarcane seeds are set and developed, even then the crop is propagated vegetatively. Explain with reasons.
3. Define the term 'clone' and give its genotypical and phenotypical characteristics.
4. What is the genetical constitution of a clone and why ?
5. Why the members of a clone are usually identical and rarely different ? Sometimes they are different, why ?
6. What is the role played by clones in plant breeding ?
7. Compare a clone, pure-line and an inbred with each other.
8. Define the clonal selection and list the names of some crops in which it is adopted.
9. What is the unit of clonal selection in rose, railway creeper, potato and sugarcane ?
10. Why the clonal selection is not adopted in crops like wheat, oat and barley for their improvement ?
11. Discuss the salient points of field technique of clonal selection and state how many years are generally taken in evolving a new strain by this method ?
12. Why the clonal selection is ineffective within a clone ? Discuss giving reasons.
13. Describe the merits and demerits of clonal selection.
14. What is the advantage of clonal selection over mass and pure-line selections ?
15. Give the origin and parents of following strains :
    Kufri Red and *Kufri Safed* Potato, Bombay green Banana and *Yuvraj Blood Red* Sweet Orange.

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CHAPTER VII

HYBRIDIZATION

Hybridization offers far greater possibilities in crop improvement than any other breeding method and is the only effective means of combining together the desirable characters of two or more varieties. Its history, although not known exactly, dates back to christmas era. It is known that the date palm was artificially pollinated by Assyrians and Babylonians as early as 700 B.C., but the main interest in hybridization was created with the discovery of sex in plants by Camerarius (1694). The first natural hybridization was recorded by Cotton Mather (1716) in corn and the first artificial plant hybrid was produced by Thomas Fairchild who crossed sweetwilliam with carnation in 1717. The hybrid obtained from this cross was vigorous and is commonly known as Fairchild's mule. The German Botanist Joseph Kolreuter (1760) was one of the first men to use hybridization practically for plant improvement and he was followed by Knight (1759-1838) and Goss (1822) in England, Gaertner (1835) in Germany, Naudin (1863) in France and others. It indicates that a large number of workers were busy in hybridization work during the eighteenth and nineteenth centuries but its significance in practical plant improvement was not clearly understood until Mendel's work came into light and laid down the basis of understanding the mechanism of inheritance in plants. Mendel onward, the hybridization had become the key method of crop improvement and, a spectacular success has been achieved by its application in all the crops all over the world.

DEFINITION AND TYPES

Hybridization consists in crossing of two or more plants which differ genetically from each other in one or more characters and can be defined as follows :

Hybridization is the method of producing new crop varieties in which two or more plants of unlike genetical constitution are crossed together.

The plants which are crossed together may belong to the same species, different species or different genera According to this relationship between parental plants, the hybridization is divided into the following categories :

(1) **Intravarietal hybridization**—The crosses are made between the plants of same variety. Such crosses are useful only in self-pollinated crops, if the variety is mixture of different genotypes, which on hybridization produces new plants showing better combinations of economic characters. In cross-pollinated crops, where the varieties are genetically heterogeneous, the controlled crossing within the varieties is only useful to maintain and improve the individual varieties.

(2) **Intervarietal hybridization**—The crosses are made between the plants belonging to two different varieties of the same species and is also known as **intraspecific hybridization.** This hybridization has been the basis of improving self-pollinated crops as well as certain cross-pollinated crops such as 'hybrid maize' which is an outstanding practical achievement in plant breeding. Most of the hybrid varieties of cereal crops, which are common at present, have been evolved by this type of hybridization.

(3) **Interspecific hybridization**—The plants of two different species belonging to the same genus are crossed together. This hybridization is between the species and within the same genus and is, therefore, also known as **intrageneric hybridization.** It is commonly used for transferring the genes of disease, insect pests and drought resistance from one species to another. All the disease, insect and drought resistant varieties in wheat, tomato, sugarcane, etc , have been evolved by this method. All the interspecific hybrids of two homozygous plants are uniform as a consequence of their identity in genetic constitution. Enhanced vigour is exhibited by the hybrids and as a general rule, they are intermediate between their parents in the sum total of their characters.

(4) **Intergeneric hybridization**—The crosses are made between the plants belonging to two different genera, *Raphanobra-*

ssica, *Rabbage*, *maize-teosinte*, *Triticale*, sugarcane-sorghum, etc., are few examples of this type of crossing. It is usually used for transferring the characters like disease, insect and drought resistance from wild genera into the cultivated plants. Hybrids produced by this method are of little or no agricultural importance except of scientific interest.

(5) **Introgressive hybridization**—In this type of hybridization one species is completely replaced by another in nature. If there is free intercrossing among the plants of two species and population of both the species is equal at the beginning of hybridization, theoretically the hybrid swarm should be distributed according to a normal frequency curve. However, if one species is more abundant than the other, the F_1 and subsequent hybrids will have more opportunities of backcrossing to that species than to the less abundant species. After a few such repeated backcrosses, most of the individuals of hybrid population will appear as pure species rather than hybrids. This absorbing of one species by another is known as introgressive hybridization.

The intra-and inter-varietal crosses are commonly met in nature followed by introgressive hybridizations, while interspecific and intergeneric hybridizations are of seldom occurrence in nature. The intra-and inter-varietal crosses can be performed easily with almost cent per cent success, while the others, though artificially practised, result in almost no success. In the intra-and intergeneric crosses the parental plants are distantly or widely related and, therefore, they are also called **wide crosses** or **distant crosses.**

APPLICATION & OBJECTIVES

Hybridization is practised in every type of crop, specially when no further improvement can be achieved in the local as well as introduced material by any other method. This situation arises only when whole of the natural occurring variation in the available material is exhausted by continuous selection.

Its use, at such times as a method of crop improvement, is commonly made with three main aims :

(1) To combine all the good characters into a single variety.

(2) To increase the range of genetic variability by introducing various recombinations of characters.

(3) To exploit and utilize the hybrid vigour.

In the first two cases the main objective sought is to create variability artificially by combining the characters of two or more than two plants, in which these valuable characters are found scattered, into one variety. This variation provides the plant breeder with basic raw material out of which selection is made to build up the new crop varieties. In the third case, the aim is to restore the vigour lost during inbreeding or to improve the level of productivity by concentrating the desired genetic factors

PREREQUISITES

Before embarking on a hybridization programme, the following requisites are to be considered and the plant breeder must be quite familiar with them.

(1) **All the requirements of the tract** either from agriculturists', local people's test or industrialists' point of view.

(2) **All the local conditions,** i.e., variations in the soil climate, agronomic practices and market and industrial conditions

(3) **Facilities** of fund, land, labour and equipment to grow and evaluate the parental material as well as hybrids.

(4) **Existing varieties of crops**, both local as well as introduced as to know how far they satisfy the requirements and then their utility as parents in the crossing programme. For this, the survey of cultivated and wild plants is carried out and the cultures of indigenous collections are maintained in the herbarium to which the foreign collections can also be added.

(5) **Plant material**, i.e., a thorough comparative information of different varieties of a crop with regard to original habitat (soil, season of cropping, water requirement and cultural practices) ; morphological and physiological peculiarities, floral biology (sex, habit and time of flowering, anthesis and dehiscence); crossing (pollination, fertilization, compatibility, sterility, inheritance of characters, etc.); adaptability to locality; resistance to diseases, insects and drought; etc., must be kept in mind.

(6) **Objectives to be attained,** i e., yield quality, hardiness, resistance, thrashability, etc.

Hybridization, in order to achieve best results, must be carried out carefully and intelligently keeping these prerequisites in view In the long run the breeder, who is most thoroughly familiar with these requisites, will get the best chance to secure the desirable improved forms quickly and easily. Over and above all these, a most essential pre-condition is that **a plant breeder must be a keen observer** so that he may select the most desirable plants easily and quickly.

HYBRIDIZATION PROCEDURE

Practical hybridization is a technical operation and requires skilled hands The various steps involved in this operation are serially described below :

(1) **Selection of parents**—The first step in hybridization is to select the plants which are to be used as parents and can supply all the desired important characters which lack in a good standard variety. They must be chosen with a great care taking into account all the objectives of work, so that the chances of selecting desirable genotypes become more. This requires the collection of material and its testing thoroughly.

As far as possible the parental plants must be selected from the local collections which are supposed to be best suited to the existing conditions. Where herbarium of local collection is not maintained, specially for a new crop or at a new station, hybridization must be delayed till the entire locality is surveyed and whole of the material is collected. If the desired parents are not available in local collection, the material can be introduced from outside. The best source of introduction is FAO which maintains a world catalogue of plant breeding materials designed to provide a breeder, in any part of the world, with viable seeds of any variety which he wants for his breeding purpose. The catalogues of wheat and rice have already been established and are being built up rapidly for other crops also. The intoduced material must be verified for their characters under the conditions where the breeding is to be done, since a crop variety resistant to a given disease in one place may be susceptible to races of that disease in another locality. Sometimes if three or four varieties are found to possess the same desired characters, all must be used

in crossing as parents. After crossing, the one which gives better performance in combination must be kept with its hybrids and others with their hybrids may be discarded.

In the selected variety also the weak, old and all the undesirable plants must be rejected, and the healthy and vigorous ones kept as parents. All the important characters to be combined must be kept in mind and the plants chosen as parents tested repeatedly for these characters.

(2) **Selfing of parents**—This is the second step consisting in artificial self-pollination of parents. It is, therefore, also designated as **artificial self-pollination** and is very essential for eliminating the undesirable characters and obtaining inbreds. The desirability of inbreds in hybridization is due to their double advantages over heterozygous plants. Firstly, they and their hybrids can be maintained easily while the heterozygous plants and their progeny are lost due to segregation. Secondly, the inbreds, due to elimination of undesirable recessive characters from them, produce better plants while hybrids obtained from the crosses of heterozygous plants have no advantage over the natural population.

Selfing is automatically performed in self-pollinated crops when they are allowed to follow their natural mode of pollination. In them the seeds of individual plant are harvested separately to isolate different inbreds from the mixed heterogeneous population. The plant breeder must know the extent of cross-pollination, which is measured by two methods in such crops. One by planting in adjacent rows the pure-breeding varieties which show distinct differences in respect of one or two known characters. Any variation in the characters, which are easily detectable in the first generation itself, denote natural crossing from adjacent rows. Count the number of plants in whole population showing these differences and calculate the percentage of natural cross-pollination. Another method by which this could be estimated is to emasculate a large number of flowers and leave them to cross-pollinate naturally. From the number of fruits or seeds set, the extent of natural crossing can be judged. If the natural cross-pollination is slight, it can be ignored and if it is excessive, the flowers must be protected by bagging to prevent the foreign

pollens from reaching to the stigmas of self-pollinating flowers. Selfing automatically takes place inside the bags.

In cross-pollinated crops, the selfing is comparatively cumbersome and the parents are artificially selfed in different ways. The dichogamous plants, such as *bajra* (*Pennisetum typhoides* S. & H.), the panicles are simply bagged and the self-pollination takes place inside the bags automatically. In monoecious plants, such as maize, both male and female are bagged separately before the emergence of silks from the cobs and dehiscence of anthers from tassels. After emergence of silks and dehiscence of anthers in bagged plants, the bagged female is pollinated with the pollens from bagged male of the same plant. **Whatever may be the way of selfing its operation must be quick, safe and inexpensive.**

Selfing is the natural mode of pollination in self-pollinated crops and, therefore, it brings no new results in them except to eliminate the natural cross-pollination and undesirable characters, if any are there. On the contrary, in cross-pollinated crops it results in many visible drastic effects as given below :

(1) Reduction in vigour and productiveness.
(2) Appearance of abnormalities.
(3) Decrease in heterozygosity.
(4) Increase in homozygosity, i.e., production of inbred lines.

The decrease in vigour and productiveness is greater in the first few generations and later it becomes lesser and lesser in each succeeding generation of selfing until an equilibrium is reached where there is no more loss of vigour and productiveness. The extent of reduction in vigour varies from line to line. Some lines so reduced in vigour that they can not be even maintained while others may continue to yield as much as 50 or 60% of the original varieties from whic' they are obtained.

The second striking effect of inbreeding is the appearance of abnormal plants such as albinos, lethals, dwarfs, disease susceptibles, steriles, fasciated, etc. They are manifested due to exploitation of harmful recessive characters while the same, though also

present in natural population, can not show their harmful effects on account of being in heterozygous condition. Only on selfing they are rendered homozygous and express their harmful effects phenotypically. The extent up to which these abnormal plants appear depends upon the amount of cross-pollination and heterozygosity occurring in the natural population Their appearance is more in the first four or five generations of selfing and by the 8th or 10th generation they all are exploited and eliminated by discarding and selection in each generation.

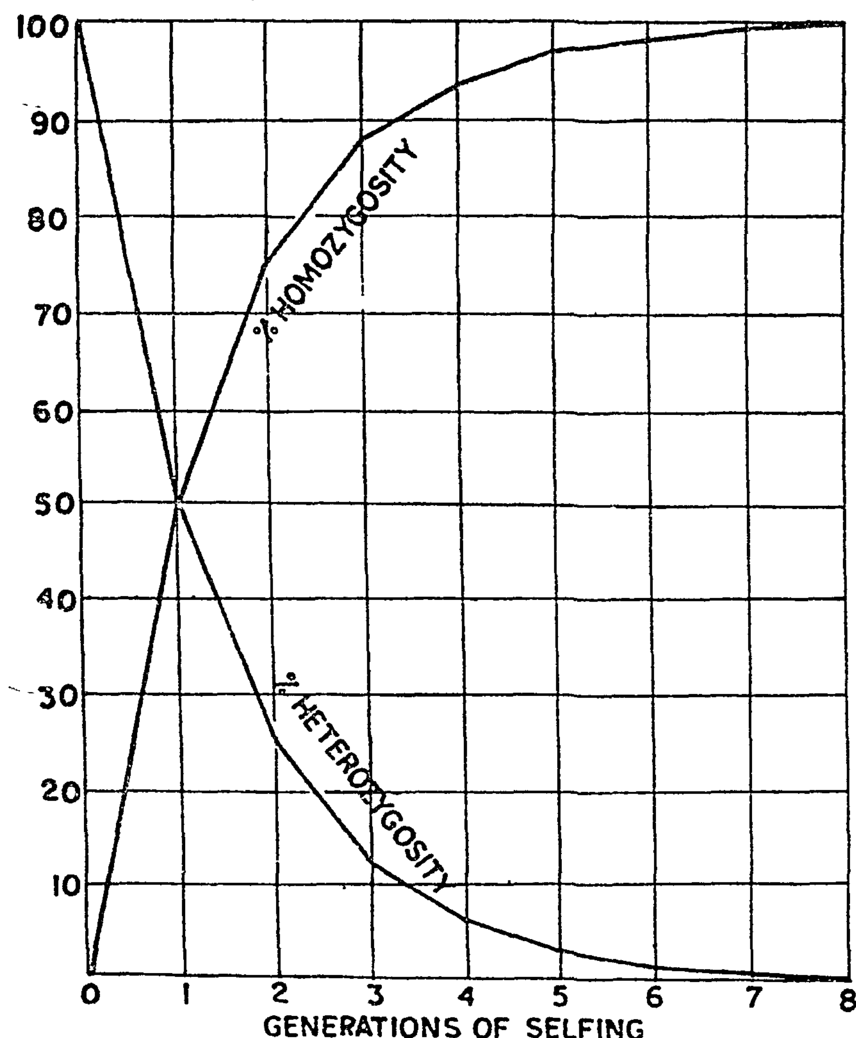


Fig. 18

Graph showing the effect of selfing upon homozygosity and heterozygosity (After Singleton W R. *Elementary Genetics*, D. Van Nostrand Co, Inc, Princeton, N J.)

Parents :— AA × aa

Generations selfed	F 1 AA	Aa	aa	AA+aa	Homo-zygosity %	Hetero-zygosity %
0		100%		0	0%	100%
1	1/4	2/4	1/4	1/2	50%	50%
2	3/8	2/8	3/8	6/8	75%	25%
3	7/16	2/16	7/16	14/16	87.5%	12.5%
4	15/32	2/32	15/32	30/32	93.75%	6 25%
5	31/64	2/64	31/64	62/64	96.875%	3.125%
6	63/128	2/128	63/128	126/128	98.45%	1.55%
7	127/256	2/256	127/256	254/256	99.225%	0.775%
8	255/512	2/512	255/512	510/512	99.612%	0.388%
9	511/1024	2/1024	511/1024	1022/1024	99.79%	0 19%
10	1023/2048	2/2048	1023/2048	2046/2048	99.905%	0.095%
n	$\frac{(2^n)-1}{2^{n+1}}$	$\frac{2}{2^{n+1}}$	$\frac{(2^n)-1}{2^{n+1}}$	$\frac{2^{n+1}-2}{2^{n+1}}$	$\frac{2^{n+1}-2}{2^{n+1}}$ or $\frac{2^n-1}{2^n}$	$\frac{2}{2^{n+1}}$ or $\frac{1}{2^n}$

Fig. 19

Increase in homozygosity with simultaneous decrease in heterozygosity

After several generations of selfing the heterozygosity is reduced more or less to zero and simultaneously the complete homozygosity is achieved. Even though the complete homozygosity in quantitative characters is virtually unattainable but, at least from theoretical point of view, a practical state of homozygosity is generally reached by 8th or 10th generation of selfing and, therefore, it is usually carried out for eight to ten years. Ultimately the selfing results in production of inbreds which are defined as "**the progeny of inbreeding**". All the plants of an inbred are alike genotypically and phenotypically ; but the plants of different inbreds differ in their agronomical, morphological and genetical characters such as time of maturity, stem strength, height, lodging resistance, disease reaction, cold and drought resistance, plant and ear features, etc. Selection among them is made during inbreeding to sort out the inbeds possessing most desirable characters. The inbreds are usually very weak and stunted in growth as compared to the natural population of cross-pollinated crops. Some are so weak that they can not be even maintained and, therefore, they are improved by the different methods of inbred improvement such as recurrent selection, convergent improvement, etc. The selected inbreds, before utilization, are tested for combining ability, both specific and general, and the most suitable ones are further utilized in the hybridization technique.

(3) Hybridization technique

The inbreds, being weak and low in yield, can not be released directly as new improved varieties and, therefore, they are combined together by hybridization technique. For this, the inbreds are grown under normal and protected conditions in the isolated plots so that they may develop properly and get full shelter against insect pests, animals, birds and diseases. The distance of isolation increases with the increase in the percentage of cross-pollination. They are sown at different dates to secure simultaneous flowering. The males and females to be crossed are marked in such a way that the dehiscence of anthers coincides the stigma receptivity. They are then carried out under the following operations :

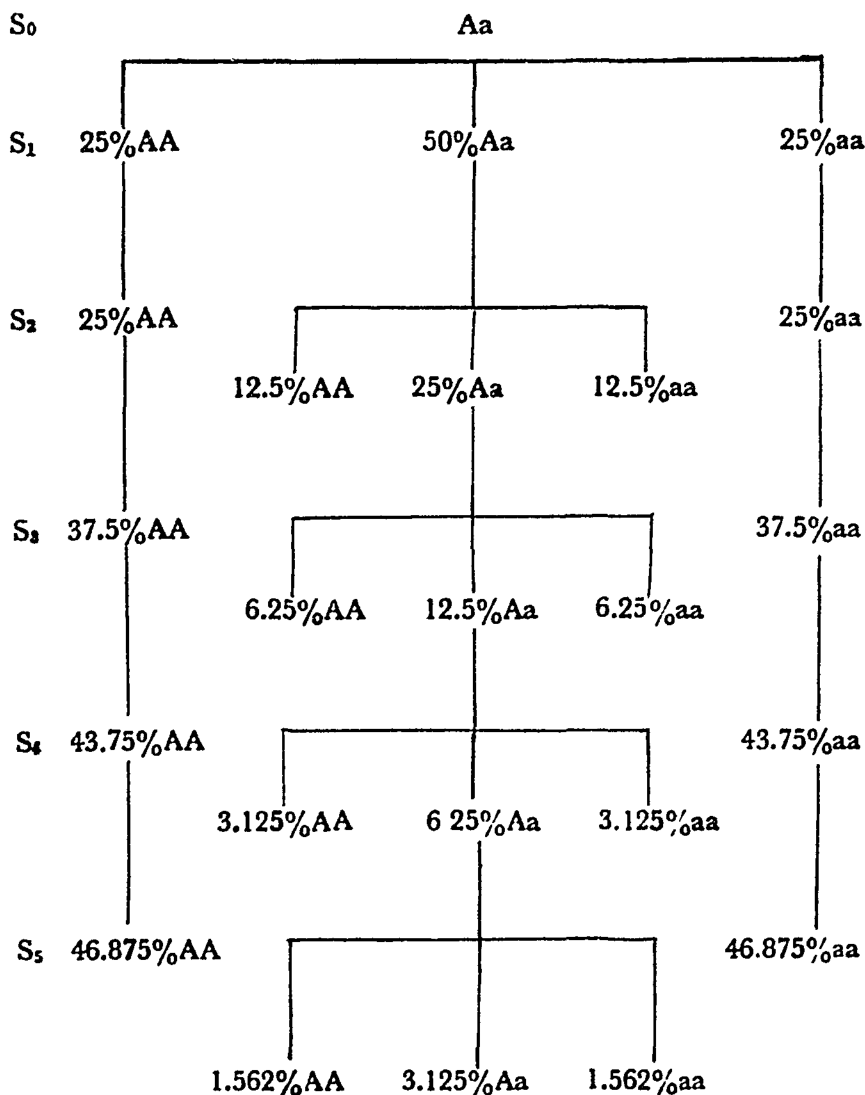


Fig 20

Illustrative diagram showing the reduction in heterozygority by 50% in each successive generation of selfing Where, So—original selfed plant, S_1—first selfed generation, S_2—second selfed generation and so on

Emasculation—This is the third step in hybridization procedure and is defined as **"the removal of stamens from female parent before they burst and have shed their pollens"**. The purpose of emasculation is to prevent self-fertilization, and, therefore, it is usually performed a few hours before the anthers ripe, dehisce and self-pollinate their stigmas. The floral buds or panicles which are expected to open on the following day are selected for the purpose of emasculation and such flowers can be easily recognised by their enlarged unopened corolla still greenish in colour and about half grown in size.

Emasculation is not needed at all in unisexual, i.e., monoecious plants but it is always necessary in bisexual plants of self- as well as cross-pollinated crops. It is a very simple operation carried out differently in different crops and some of the common methods of emasculation are described below :

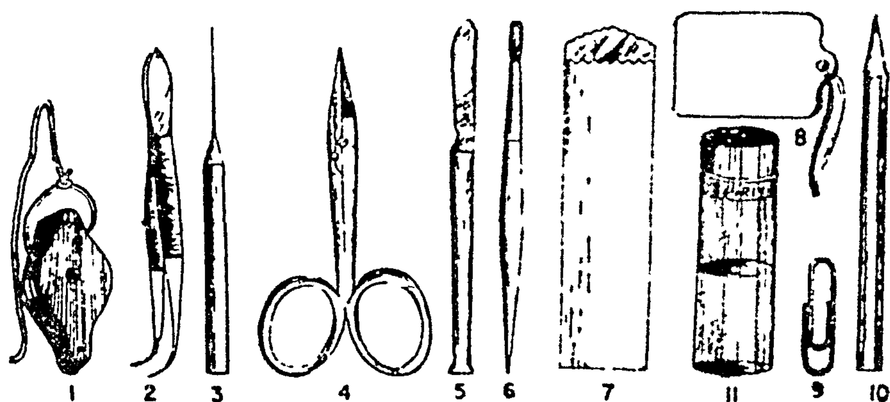


Fig 21

Plant breeder's kit containing the equipment commonly used in emasculation and crossing. 1—Pocket lens, 2—Forcep, 3—Needle, 4—Scissors 5—Scalpel 6—Camel's hair brush, 7—Bag, 8—Label and tag, 9—U-pin 10—Pencil, 11—Spirit.

1. *Forcep or Scissor method*—It consists in opening of flower and removing of the stamens which can be accomplished easily by using a pair of forceps or scissor (Fig. 22). The exact technique of operation is very simple varying from crop to crop. This technique of emasculation is generaly used with those plants which

bear large flowers such as wheat, barley, cotton, etc. The commonly used tools have been given in Fig. 21.

2. *Hot or cold water and alcohol emasculation*—The removal of stamens by forcep or scissors is very tedious and painstaking work in the plants having small sized flowers such as rice, sorghum and *bajra.* In them the emasculation is done by dipping the panicles in hot water having a desired temperature for a definite period. In actual practice a thermal jug is filled with water having the desired temperature (45° to 53° C) and taken into the field. The flowers or panicles to be emasculated are immersed in the jug for a particular time (1 to 10 minutes) varying from species to species. Similarly the cold water or alcohol emasculation is carried out (Fig. 22).

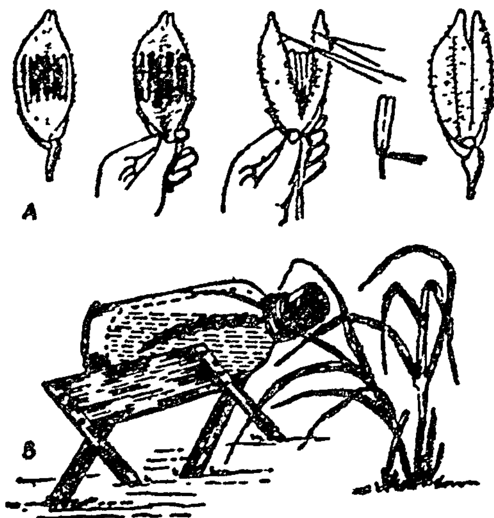


Fig. 22
Emasculation in Rice. A—Forcep method and B—Hot water method.

3. *Male-sterility method*—In some self-pollinated crops such as barley, sorghum, onion, and *bajra* the emasculation operation may be eliminated by the use of male-sterile plants which have sterile anthers and do not produce any viable pollens. The sterility may be due to cytoplasmic and genetic causes. The male-sterility conditioned by the recessive genes is first introduced into the plants to be used as females by backcrossing and the emasculation in them is then not needed at all.

Male-sterility may also be induced by spraying some chemicals such as 2, 4-D, naphthlene acetic acid (NAA), maleic-hydrazide (MA) and tri-iodobenzoic acid.

Bagging—This is the fourth step and is completed with the emasculation in bisexual plants and before the stigma receptivity and dehiscence of the anthers in unisexual plants. Both male and female flowers are bagged separately to prevent contamination in staminate flowers and cross-pollination in pistillate flowers. The pollens are also collected only from already bagged males for crossing purpose.



Fig. 23

Different methods of bagging.

The bagging is usually done in the evening of previous day of crossing, since most of the crops become receptive in the morning. The bags are kept on the females as such till seed setting is complete while in males they are removed as soon as the crossing is over.

The bags, with which bagging is done, are made up of different material such as paper, cloth, plastic, parchment, glassine, polyethylene or celophane. The size of bags is according to the size of flowers of a crop in which they are to be used. In many cases ordinary muslin cloth and paper bags are satisfactory. The thin paper bags immersed in oil or paraffin are best

for withstanding the insect attacks as well as for the plants having very delicate flowers. In some cases, it is essential to puncture the bags with numerous minute holes to provide ventilation and prevent moulds' development inside the envelope. Many special devices such as cylindrical muslin cloth bags, glass or celluloid cylinders plugged with cotton and with firm support, are used occasionally. The bags are tied to the base either by threads, copper wires or pins specially designed for stitching these bags.

Crossing—It is the fifth step and is antithesis of inbreeding. It can be defined as **"the artificial cross-pollination between the genetically unlike plants"**. Its operation consists in collecting of the viable pollens or anthers from the desired male parent and transferring them on to the stigma of desired emasculated female parent.

The pollens or anthers are collected either in petridishes as in wheat, cotton, etc., or in paper bags as in maize, just after the dehiscence. The bag is temporarily removed from the female parent and the collected pollens are either brushed or dusted on its stigma. In wheat, instead of of brushing and dusting, the whole anthers are inserted inside the florets with the help of forcep. After crossing, the flowers are again bagged. As a precaution, it is always advisable to make the crossing immediately after collecting the pollens. However, if it is not possible, the pollens must be stored at a cool temperature so that they may not die on account of high temperature at which the pollens are usually viable for very less time or even for few minutes.

In crops like *bajra* and *jowar*, the hand cross-pollination is very tedious and painstaking due to the small size of flowers. In such crops, the pollen parent is either grown by the side of mother parent or is kept transplanted into a pot (pot method) and brought close to the emasculated female parent at the time of crossing. Both the male and female panicles are enclosed in one bag and crossing takes place inside the bag automatically.

The crossing is normally done at the time of anthers' dehiscence and stigmas' receptivity. The dehiscence of anthers can easily be recognised by the yellowish colour containing a powdery

mass and flower opening. The stigma receptivity is evidenced by the full development of stigma with the secretion of a viscid fluid on its surface. This condition in most of the crops approaches in the morning at different times in different crops. The crossing must, therefore, be done on the same day morning when the female is emasculated, or one or two days later, depending upon the approach and durability of stigma receptivity.

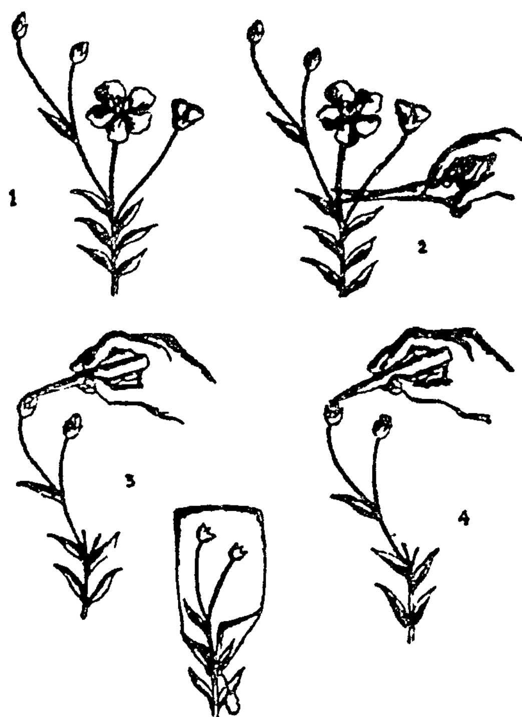


Fig. 24

Hybridization technique in linseed
1. A branch with flowers and buds
2 Removal of unwanted and unsuitable buds
3. Removal of corolla for emasculation
4. Emasculation
5 Bagging and tagging after emasculation and crossing.

Labelling—The crossed flowers are properly tagged and labelled The labelling is done either on the bag itself or on the labels specially designed for this purpose. They are of different sizes and shapes, and either may be purchased from the market or made in the laboratory from the ordinary, but somewhat hard, paper They are tagged to bags with the help of threads. The

labelling on them must be as brief as possible but complete, bearing the following information ;

(1) Number referring to the field record.
(2) Date of emasculation.
(3) Date of crossing.
(4) Details of parents, male and female.

The first and second information are entered with the emasculation, while the third and fourth steps are entered after crossing. All other necessary particulars must be entered in a handy field-record book in which the observations are also recorded from time to time.

(4) **Harvesting hybrid seeds and raising F_1 generation**—This is the sixth step in which, first of all, the bags are removed and the crossed heads of desirable characters are harvested and collected with their attached labels separately in envelopes. After complete drying, they are threshed individually and preserved as such. In the coming season, these seeds are sown separately to raise the F_1 generation. The plants of F_1 generation are progenies of crossed seeds and, therefore, are hybrids (**the progenies of a cross between genetically unlike plants which may be inbreds, clones, varieties or other populations**). All the plants of F_1, although heterozygous, have similar genetical constitution and look exactly alike. They may or may not show hybrid vigour. The term 'hybrid variety' was used for many years to identify varieties developed by hybridization. This term is now used only for those varieties that express hybrid vigour., i.e., increased growth, size, yield or function over the mean of parents.

(5) **Hybridization methods**—This is the seventh step consisting in handling of F_1 and subsequent generations by different selection methods of hybridization which are different for self-and cross-pollinated crops as listed below :

Self-pollinated crops—Every selection method has its application under some specific circumstances for definite advantages. The detailed description of everyone is given below with application, advantages and limits.

(1) Pedigree method.—The individual plants are selected from the F_2 population on the basis of desired characters. The number of

plants to be selected depends upon the number of important characters involved, the importance of breeding problem, and the assistance and facilities available. These plants are harvested and threshed separately, and sown in the separate rows in the next year to raise the F_2 generation. In F_2 different types of plants appear which do not resemble each other and represent all the possible combinations of genes from the parental strain entering this cross. Hence, the larger the F_1 population grows, the greater are the chances of obtaining the desirable gene combination. The disease resistance is also judged in this population by subjecting all the plants to artificial epidemics either in the green house or field. The plants possessing desirable characters and found disease resistant are saved, harvested and threshed separately, and the produce of each plant is sown in a separate row in the next year to raise F_3 generation. F_3 population is handled in the same way as F_2 except that fewer plants are selected. This process is continued up to F_4 or F_5 generation. At F_6, due to successive self-pollination, most of the lines become homozygous and fairly uniform. The plants uniform in desired characters are harvested and bulked together to constitute a variety. Similarly different varieties are produced and run into comparative trials. After adequate trials and testing, the seed of superior variety is multiplied and distributed to farmers. This whole process takes about 10 to 13 years.

The pedigree method is well suited to those crops where the characters to be combined in crosses can be easily seen and recognized, as awned or awnless character and where the individual plants in a crop can be harvested conveniently.

The pedigree method is the quickest one and a new variety can be selected and well tested by the time it reaches its 9th generation after cross. It may also allow the plant breeder to obtain genetic information not possible in any other method. With this, it is also most expensive and disadvantageous due to consumption of more attention and labour for keeping the clear pedigree record of each selected plant separately in the early generations. At plant breeding stations, where usually a large number of crosses

are handled simultaneously, it is impossible to pay and put so much attention and labour for keeping clear pedigree records. For this, an another method known as bulk method is used to save the labour.

(2) Bulk method.—This system of breeding differs from the pedigree method in that the F_3 plants are not maintained separately but are bulked together to form a single F_3 population. In F_3, again the suitable plants are selected, collected and bulked together. This bulking is done for six generations. In F_6, the desired individuals are selected and harvested separately. The produce of each plant is kept separate and carried out under comparative trials. The best performers are released as new varieties.

Bulk method is a simple, convenient and inexpensive method. It takes more time but minimizes the labour as the plants are not paid any individual attention. Sometimes the plant breeder has no option except to follow this method.

The table below shows the different steps comparatively involved in both pedigree and bulk methods.

Table 5. Comparison in between pedigree method and bulk method.

Year	Pedigree method	Bulk method
1.	Crossing.	Crossing.
2.	F_1 is raised.	F_1 is raised.
3.	F_2 is grown and the desirable heads are selected from the segregates.	Desirable head are selected from F_2 grown population.
4.	F_3 is raised in which every head is grown in one separate row (head-row) and the desirable panicles are selected.	F_3 is grown in bulk plot and about 100 desirable heads are selected.
5.	F_4 head-rows are grown and desirable heads are selected.	F_4 is grown in a bulk plot and 100 heads are selected.

Year	Pedigree method	Bulk method
6.	F_5 head-rows or blocks of three rows of each head are grown with every fifth row or every third block as check.	F_5 is grown in a bulk plot and 100 heads are selected.
7.	For F_6, three-row blocks of each selected head are grown with checks as above.	For F_6, selected heads are grown separately in row and the desired ones are selected.
8.	For F_7, three-row blocks of each selection are raised with checks as above.	For F_7, 20-row blocks from 2 or 3 selections are raised.
9.	As in the 8th year.	Selected heads are sown in small plots with checks.
10	The selected varieties are run into replicated yield trial plots with checks in different localities (Also Foundation seed production)	As in the 9th year.
11.	Seeds are multiplied (Registered seed).	The selected heads are run into replicated yield trial plots with checks.
12.	Distributed to Farmers. (Commercial seed).	Yield trials are conducted on larger plots in different localities.
13	Market crop.	Seeds are multiplied (Registered seed).
14.		Seeds are distributed to farmers.
15		Market crop

These steps are applicable in every crop with some modifications in them somewhere here and there.

Table 6. Differences between pedigree and bulk methods

S. No.	Pedigree method	Bulk method
1.	Individual plants are selected and bulked at the end	The selected plants are bulked and individuals are tested separately at the end.
2.	Less time is required in producing a variety.	More time is required in producing a variety.
3.	It is tedious and complicated.	It is simple and convenient.
4.	Most expensive.	Inexpensive.

(2) *Backross method* :—The backross method is entirely different from both pedigree and bulk methods and was first proposed by Harlan and Pope (1922) as a method of breeding small grains. This method is employed in improvement of both self and cross-pollinated crops where varieties are deficient in one or two aspects particularly for transferring a single simply inherited character like disease, frost or drought resistance, and earliness from an undesirable variety to a good commercial variety. In the backcross system the desirable variety, called as **recurrent or recipient parent,** is crossed to an undesirable variety, called as **donor parent**, possessing a character which lacks in the good parents. F_1 plants, instead of permitting to self-pollinate as in pedgiree or bulk method, are crossed with the recurrent parent and, therefore, it is designated as "Backcross method". The purpose of backcrossing is to recover the genotype of recurrent parent with disease resistance. The progenies of first backcross designated as BC_1 and containing the good character from donor parent are again backcrossed to the recurrent parent. This process of selection of plants with desired characters and then backcrossing is continued for several generations usually up to BC_5 or BC_6. In each backcross generation, the plants possessing desirable characters of non-recurrent parent are primarily selected. At the end of BC_6, the selected plants are self-pollinated to make

the population homozygous in combined characters. If the selection is made properly, the plants obtained at the end, must very closely match with the original parent except differing from it only in desired gene incorporated from the donor parent.

Suppose the variety "A" is very good in all characters but disease susceptible and the variety "B" is disease resistant but very poor in all other characters. It is needed to transfer the disease resistance from **B** to **A** without adversely affecting its good qualities. **B** is then **donor or non-recurring** parent and **A** is **recipient or recurring parent.** The procedure is as follows : —

(1) Cross the selected plants of **A** and **B**, **A** as female and **B** as male and raise F_1. Note the plants possessing desired characters of **A** with disease resistance of **B** and collect them.

(2) Cross F_1 (**A**×**B**) to **A**, F_1 (A×B) as female and **A** as male, and raise the backcross F_1 plants, i. e., **BC_1** (Backcross first generation). Also inject them artificially with disease spores. Select the plants possessing desired characters of **A** with disease resistance of **B**.

(3) Backcross the selected **BC_1** plants again to **A** and raise **BC_2** and selection is further made similarly as in step 2.

(4) Carry on this operation of backcrossing to **A** and selection till a desirable type having good qualities of **A** and disease resistance of **B** is obtained.

This type of transference of some genes of one species, as **B** in this case, into the genotype of another species, as **A** in this case, by crossing is also known as **introgressive hybridization.**

(5) Self-pollinate the finally selected plants so that they may be made homozygous for the disease resistance.

(6) The different such selected selfed lines can be crossed together to restore hybrid vigour.

When two characters of a donor variety have to be transferred, it is advisable to transfer each character in a separate programme.

Usually, the backcross method is used for transferring disease resistance from one variety to another and disease resistance may be dependent on a dominant or recessive character. If it is determined by a dominant gene it is relatively easy to transfer with a backcross in each generation. If it is due to recessive gene, each backcross is grown to F_2 to permit the identification of homozygous recessive genotype. Another way is to backcross twice or thrice in successive generations and to grow the products of second or third backcross to find plants homozygous for recessive gene under transfer.

When a quantitative character is to be transferred 'each backcross generation may be grown through to F_3 lines before the next backcross is made. In addition, if its heritability is low and and serveral genes are involved, backcross F_2 and F_3 populations will have to be large (Briggs and knowles 1967)'.

Backcross method has got many advantages as (1) independence from environment, i.e., it can be used in any environment where the plant will grow and character under transfer will express itself, (2) no need of evaluation of agronomic performance, i.e., backcross derived varieties can be safely released to growers without evaluation of yield, adaption or quality (3) it is rapid (4) it requires a small number of plants, (5) it is repeatable, and (6) it is predictable. Its greatest advantage has been in the production of disease-resistant varieties.

Backcross breeding does not permit the achievement of unusual combinations of genes from two or more varieties which is the most important drawback of this method

(4) *Multiple or composite cross*—It consists in crossing of several pure-lines together. The selected pure-lines are first combined into crosses as A×B, C×D, E×F, G×H, and so on. F_1 of these single crosses are then combined into double crosses as (A×B) × (C×D) and (E×F) × (G×H). Finally the F_1 s of double crosses are crossed with each other to produce the hybrids [(A×B) × (C×D)] × [(E×F) × (G×H)]. This cross is known as multiple cross and further breeding in these hybrids is carried out according to either pedigree or bulk method as described

previously in this chapter. Multiple cross in self-pollinated crop is used when three or four monogenic characters scattered in three or four different varieties are to be combined into one as the resistance to all three rusts of wheat into N. P. 809 variety from different strains.

Cross-pollinated crops—The inbreds are combined in any one of the following crosses and released as improved strains.

(*1*) *Single cross* (A × B)—This is the cross between two inbreds, such as A × B or C × D and was proposed by Shull (1909). Its hybrid seed, which is the first generation product, is distributed to farmers for raising the crop. A single cross is made by planting two rows of female lines to one row of male line alternatively so that two-third of the field can produce hybrid seed for sale. The number of possible different single crosses produced from various inbreds can be calculated by a simple formula given below :

$$\text{Number of single crosses} = \frac{n\ (n-1)}{2}$$

where, n = number of inbreds.

Example : If four inbreds, A, B, C and D, are involved, the number of single crosses produced will be six as calculated below by the above formula :

$n=4$, ∴ No. of single crosses $= \frac{4 \times 3}{2} = 6$, i. e., A × B, A × C, A × D, B × C, B × D, and C × D. Similarly, if inbreds are six, the single crosses will be $= \frac{6 \times 5}{2} = 15$, i. e., A × B, A × C, A × D, A × E, A × F, B × C, B × D, B × E, B × F, C × D, C × E, C × F, D × E, D × F and E × F

Single crosses give the maximum degree of hybrid vigour and produce most uniform plants and ears. For this reason, they are specially used for production of sweet corn for canning or freezing in America On the contrary, their kernels are very small in size and seeds are poorly developed which involve high cost of seed production on commercial scale. The single crosses are, therefore, commercially undesirable but needed

primarily as foundation hybrids for double and three-way crosses as well as to predict the performance of double crosses.

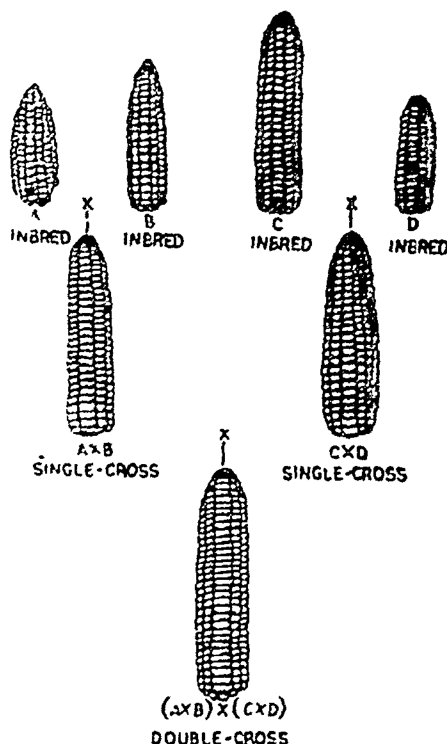


Fig 25

An illustration of inbreds, single crosses and double cross Note the size of cobs at different stages for comparison of various hybrids with inbreds.

(2) *Three-way cross* (A × B) × C — This is a cross between a single cross used as female and an inbred used as male, i.e., it involves three inbreds. The single cross and the inbred are planted in the same way as the inbreds in single cross. The advantage of a three-way cross is the use of vigorous hybrid of first generation as female in order to maximize the yield of hybrid seed as well as to obtain seeds of normal kernel size. A disadvantage of three-way cross is the difficulty of obtaining high pollen production from the inbred male parent. It is intermediate between single and double crosses in its characteristics.

(3) *Double cross* (A×B)×(C×D)—This is the cross between two single crosses involving four different inbreds, Jones (1918). An inbred involved in one single cross must not be included in the another single cross of the double cross parents. It is also advisable to combine the similar or closely related inbreds in the single-crosses and the different or distantly related inbreds in the double crosses. A double cross is produced by alternate planting of two single cross plants in an isolated plot and detasselling of the single cross used as female parent. Usually the ratio of the female to male rows has been 4 : 1 so that 80 per cent of the field produces seed for sale.

The number of double crosses, from various inbreds entering the double crosses, is calculated by the following formula:

$$\text{Number of double crosses} = \frac{n(n-1)(n-2)(n-3)}{8}$$

Where, n=number of inbreds involved.

Example: If A,B,C and D are four inbreds, the number of all the possible double crosses will be $= \frac{4\times3\times2\times1}{8} = 3$, i. e., [1] (A × B) × (C × D), [2] (A × C) × (B × D) and [3] (A × D) × (B × C).

Double crosses are the most widely used commercial hybrids. All the hybrid seeds of maize distributed to farmers for cultivation are nothing but double crosses. They give very high yields in small land without any increase in the cost of production. Being produced in large quantities, they can meet the demand of farmers at a price which farmers can afford to pay. Although double crosses have been more variable than single crosses, the variability has often given them wider adaptation.

(4) *Top-cross* or *Inbred-variety cross* (A×Variety)—This is a combination between an open-pollinated variety and inbred line. Either the inbred or the variety may be used as female parent, but to use variety as female is preferable. The top-crosses are used mostly for testing the combining ability of inbreds and not for commercial hybrid seed production.

(5) *Synthetic cross*—This is the combination of a number of inbreds, sibbed lines, or clones to utilize the desirable characters from

different sources. It eliminates the necessity of producing seeds in an isolated plot because they are allowed to pollinate naturally. Not a single synthetic variety has been obtained so far which proved superior or even equal to the double crosses in hybrid vigour but it is less costly in seed production and can be used for a number of generations which is not possible in a hybrid variety. Even then the synthetic varieties are better than open-pollinated varieties because, firstly, at least they exhibit some amount of heterosis, and secondly they are more flexible than double crosses and, therfore, are more adapted to the changeable growing conditions of the areas. The synthetic crosses have been utilized in forage crops where floral structure causes difficulties in artificial pollination.

Wright (1922) developed a formula to predict the performance of synthetic varieties expected in F_2, and is applicable when inbreds are used as parents not the clones or other populations :

$$F_2 = \bar{F}_1 - \frac{(\bar{F}_1 - \bar{P})}{n}$$

Where F_2 is the expected performance of synthetic variety in F_2; $\bar{F}_1$ is the average or mean performance of F_1 hybrids from all combinations of the inbred-lines; $\bar{P}$ is the average performance of inbreds, and n is the number of inbreds. The formula, in effects, says that the yield in F_2 and subsequent generations will be $\frac{1}{n}$ less than that portion of yield of the F_1 attributed to heterosis. The so predicted values of F_2 performance help in developing a synthetic variety but they are not, indeed, a substitute for tests of its actual performance.

In developing a synthetic variety it is essential to decide on the number of inbred lines that will give the optimum values of n, $\bar{P}$ and $\bar{F}_1$. Kinman and Sprague (1945) concluded that the expected yield of F_2 increased with increasing numbers of inbred lines up to 5 or 6, and decreased as the lines increased from 6 to 10. Thus the number of inbreds involved varies from 4 to 10 and it is also said that the optimum number would be closer to ten, if all were to combine well together.

(6) **Trials, multiplication and distribution** :—The eighth step is testing, multiplication and distribution of so produced hy-

brid varieties. The testing is done at various regional research stations by research workers. The seeds are multiplied at seed multiplication farms situated at different localities and distributed to farmers through co-operative societies, panchayats, etc. The whole process of testing and multiplication consumes about 5 to 7 years.

Table 7. A comparative look on hybrid, composite and synthetic varieties of cross-pollinated crops

Comparison in	*Hybrid variety*	*Composite variety*	*Synthetic variety*
1. Parents	2 to 4 inbreds	6 or more inbreds	4 to 10 inbreds
2. Pollination	Controlled, i. e., between desired inbreds	Controlled i.e., between desired inbreds	At random
3. Genetic base	Restricted gene base	Broad genetic base	Broad genetic base
4. Hybrid vigour	More	More	Less than hybrid and composite varieties
5. Seed production	Expensive	Most Expensive	Less Expensive than both
6. Distribution	Fresh seeds every year to farmers	No need to distribute seeds to farmers every year	No need to distribute fresh seeds to farmers every year
7. Maintenance	Difficult	More difficult	Easier
8. Popularity	Most popular	Not popular but now trend is changing towards them	Not popular

DIFFICULTIES AND PRECAUTIONS

(1) Isolation of suitable parents and hybrids—Most difficult part of the hybridization is to recognize and isolate the desi-

rable inbreds to be used as parents and the hybrids to constitute the variety finally. This requires careful observation, through testing of all selected plants and their progenies, subjection of selected lines to diversities such as disease, drought or cold; accurate and exhaustive note-taking and record keeping, and finally the up-to-date available information and trained plant breeder for identifying the potentially desirable lines with very high degree of accuracy.

(2) **Different times of maturity**—Always the plants grown in the same season are selected for crossing, but they may not flower together due to difference in their time of maturity. This is a common obstacle faced practically during hybridization and can be overcome by adjusting the sowing period in such a way that both the male and female parents flower simultaneouly. When this is not feasible, the pollens may be preserved. There may be advised various other ways of overcoming difference in time of sexual maturity For example one of the parents may be retarded in flowering by stimulating effects of various chemical substances as sulphuric acid in sugarcane (Verret, 1925). Further, this difficulty may be got around by regulating the day length as reported by Emerson (1924) in teosinte.

(3) **Susceptibility to mutilations**—During emasculation and crossing, the floral parts are touched with hands, anthers are removed and sometimes even some portions of flowers are removed totally to facilitate the hybridization. Due to these, the flowers are subjected to mutilations and the species vary in the amount of mutilations they can tolerate in the process of hybridization. For example, small flowered legumes are among the most difficult species to hybridize because the damaging mutilation is almost impossible to avoid as a consequence of size and structure of flowers. Some plants are susceptible even to the removal of anthers from the ends of filaments. In such cases, the flowers are handled carefully and special ways of breeding are adopted depending upon the structure of flower.

(4) **Incompatibility and sterility**—The incompatibility and hybrid sterility are common in both interspecific and intergeneric

crosses. Incompatibility may be due to many causes ranging from simple morphological differences to complex physiological relations. The simplest probable cause of unsuccessful crosses is failure of viable pollens to germinate and this trouble can be controlled by the application of a film of water of weak sugar solution to the surface of stigma before pollination. The failure of fertilization may be due to longer style than the pollen tube and thicker pollen tubes than the cavity of style and both can be covered up by making the cross in reciprocal direction and by shortening the style artificially.

In jute, tobacco and tomato, the voluable hybrids have been made through the inactivation of interspecific incompatibility mechanism by using the irradiated and X-rayed pollens in making the crosses.

Similarly the hybrid sterility is the main handicap in wide crosses. The cause of sterility are numerous, all originating from genetic imbalance which is responsible for meiotic irregularities causing hybrid inviability. It may be overcome by using the species with larger chromosome number as seed parent. Hybrid sterility is very rare in intervarietal crosses and, if sometimes is there, it is due to the genetic and zygotic lethals.



Fig. 26

Interspecific hybridization in tomato: (1) *Lycpoersicum esculentum*, (2) *L pimpinellifolium*, (3) F1 hybrid and (4) Backcross. This cross gave the variety *Pusa Red Plum* in tomato.

(*After Ind J Genet Pl Brd*)

The most favourable condition to ensure crossibility, compatibility and fertility are viable pollens, receptive stigma, proper size

and thickness of tube and style, more or less equal number of chromosomes in both parents, morphological and physiological similarities, and optimum conditions for flowering and fruiting.

EFFECT OF HYBRIDIZATION

Hybridization results in **hybrid vigour** which is the increased growth, size, yield, or function of hybrids over the mean of parents. All the hybrids between two inbreds show same amount of hybrid vigour since they all are similar genetically, while the hybrids from different inbreds show variation in amount of hybrid vigour because the various inbred lines differ in the type and number of characters they possess. Hybrids from closely related inbreds give less hybrid vigour than those from widely related inbreds. Unfortunately, not all the crosses, may be between closely or widely related plants, produce good hybrids. The greater the number of desirable traits present in the inbreds, the greater will be the likelihood of producing outstanding hybrids.

Hybridization has given rise to many crops such as cannas, dehlias, roses, poppies, violets, rhododendrons, *Coffea congensis* and *Abelia grandifolia.* Many of the field crops like wheat, sugarcane, cotton, tobacco, oats, *Brassia juncea*, *Brassica napus*, *Brassica carinata*, *Sesamum indicatum* etc., are also hybrids originally derived from crosses between different species.

Wide crosses exhibit sterility and break down of quality and test in hybrids and, therefore, achievement by them is greatest only in horticultural plants specially ornamentals where, instead of quality and test, novelty is the main demand and the once obtained superior hybrids can be maintained by vegetative propagation. In sugarcane also all the varieties have been produced by these crosses, since they can be preserved as such by vegetative propagation. The interspecific and intergeneric crosses have been of least importance in cereals, fibrous and vegetable crops because the quality and test are most important characters to be kept in them which are spoiled if wide hybridization is adopted. In such crops, wide crosses have been used to obtain the varieties, possessing early maturity and resistance for disease, drought, insects, etc., through careful combination of hybridization and selection.

ACHIEVEMENTS

In the improvement of cereals and vegetable crops the inter-varietal hybridization has been commonly practised and almost all the varieties evolved in them are the achievements of these crosses.

These strains possess most of the desirable qualities and are playing an important role in increasing the food production. The losses caused by rusts in wheat have more or less been overcome by the rust resistant varieties and whole acreage of wheat is now under the improved strains. In sugarcane, 90% of the total acreage has come under Coimbatore varieties and the production has been increased by 50% over the figures obtained for old varieties. In case of cotton, the improved strains are grown in more than 75% of the total cotton acreage. Similarly in maize and other crops, the yield per acre has been increased and the food production of country has been enhanced tremendously on account of hybrid varieties.



Fig 27

Bajra hybrid variety HB-1 (23A×S 350) bred at P. A. U. Ludhiana by Dr. D S. Athwal (*By courtesy of Dr M. S Swaminathan*).

Table 8. Important varieties of different crops evolved by hybridization

S. No. 1	*Crop* 2	*Varieties of intervarietal origin* 3	*Varieties of interspecific origin* 4	*Intergeneric crosses & varieties* 5
1.	**Wheat**			
	(*Triticum aestivum* L.)	N.P. 165, N.P. 710 (N P. 52× N.P. 165), N.P. 718 (N.P. 52×N.P. 165), N.P. 783, N.P. 784, N P. 785, N P. 786, N P. 789, N.P. 790, N.P. 797, N.P. 798, N.P. 799, N.P. 809. [Democrat×C. 518) ×(Spalding's Prolific ×N.P. 114)× E 220], N.P 325, N.P. 828, C. 281 (C. 591×N.P. 4), C. 285 (C. 228×B 256 G- Kenya), R. S. 31-1 (Pb. C. 591×Jaipur Red Local)	Niphad 4 (*Motia*× Khapli ×N.P. 4).	
	(*Triticum dicoccum*)	N.P. 201 (N.P. 200×E.	2774).	
	(*Triticum durum*)	Hyb. 38 (Ao. 13×E. 220). N.P. 412 (Ekdania 69×	Gazra).	
2.	**Cotton**			
	(*Gossypium arboreum*)	Virnar (N.R. 5×Jarila), Maljari (Malvi 9×Jarlia) H. 420 (Bani×*cernuum*).	170-Co. 2 or Deviraj (*G. hirsutum*×*G. arboreum*). 134-Co. 2-M. or Devitej(*G. hirsutum*×*G. herbaceum.*).	

(*contd.*)

S. No.	Crop	Varieties of intervarietal origin	Varieties of interspecific origin	Intergeneric crosses & varieties
	(Gossypium herbaceum)	Kalyan (Wagad 8 × Seg. 22-3-1-3 × Wagad 8), Vijay (B. D. 8 × Goghari A. 26 × B.D 8), Digvijay (Vijay × 1027 A. L. F. × Vijay), Vijalapa (Vijay × Vijay × 1027 A.L.F.).	I.S.C 67 (*G. hirsutum* × *G. arboreum*).	
	(Gossypium hirsutum)	Co. 4 (Co. 2 × A. 12), Laxmi (Gadag 1 × Co. 2).	MCU. 2 (Multiple inter-specific cross), M.A. 2, H. 190.	
3	**Maize** *(Zea mays L.)*	Ganga Hybrid Maka No. 101, Ganga Hybrid Maka No. 1, Ranjit Hybrid Maka, Deccan Hybrid Maka, Sweet Maize Hybrid No 1, Ganga safed 2, Ganga 3, Himalayan 123, Hi-starch.		
4.	**Potato** *(Solanum tuberosum L.)*	Hyb. 9, Hyb. 19, Hybrid 45, Hyb. 208, Hyb. 209.	Hyb. No. 2236, Hyb. No. 1151, Hyb. No. 2186, Hyb. No. 2287, Kufri Kuber (*S. curtilobum* × *S. andigenum* × *S. tuberosum*), Kufri Sindhuri (K. Red × K. Kundan).	

5.	**Sugarcane** (*Saccharum spp.*)		Co. 312, Co. 313, Co. 419, Co. 421, Co. 449, Co. 527, Co. 622, B.O. 10, B.O. 11, B.O. 21, B.O. 22, H.M. 645, H. 32-8560.	Sugarcane × Bamboo, Sugarcane × Maize, Sugarcane × Sorghum= Co. 356, Sugarcane × *Euchlaena maxica*= H.M. 661.
6.	**Rice** (*Oryza sativa* L.)	Adt. 20, Adt. 25, T.K.M. 6, S. 1086, S. 1088, S. 1089, T. 136, T. 137, L. 12 (L.N. 41 × C.P1), P. 502, R. 575 (R. J. 100×C P. 1).	Co. 31, I.J-1.	
7.	**Bajra** (*Pennisetum typhoides* S. & H.)	Hyb. X-1, Hyb. X-2, Hyb. X-3, Niphad Hybrid, HB-1 (23A × S. 350).		
8	**Napier grass**		Pusa Giant Napier (*Pennisetum typhoides* × *P. purpureum*), Pusa Napier 1, Pusa Napier 2.	

(*contd.*)

S. No.	Crop	Varieties of intervarietal origin	Varieties of interspecific origin	Intergeneric crosses & varieties
9.	**Jowar** (*Sorghum spp.*)	Co. 12, Co. 18 (Co. 9×Juicy Stalked Mutant), Co. 20. R. S. 610, R. S. 630, CHS-1.		
10.	**Tobacco** (*Nicotiana rustica*)	N.P. 219, N.P. 220, N.P. 222 } N.P. 18 × A Canadian Variety.		
11.	**Linseed** (*Linum usitatissimum* L.)	R.R. 37, R.R. 38, R.R. 40, R.R. 45, R.R. 197, R.R. 204, R.R. 236, R.R. 262, R R 272, H. 397 (T. 491 × T. 1193-1), H. 603 (T. 491 × T. 1193-2)-BR. 1 (Sabour 6 × N.P. 121), BR. 2. (N.P. 112 × N.P. 121).		
12.	**Sarson** (*Brassica compestris* var. *yellow sarson*)	T 10 S 13, BB 1—1 B, BB 1—2 B, Y.S. 151.		
13.	**Groundnut** (*Arachis hypogaea* L.)	C. 501 (D. 3×A.H. 477), A.H. 6481, A. H. 6608 (H. G. 1 × Native 'Tanganyika'), A. H. 6614, A. H. 6615 ('Spanish Bombay' × Native 'Tanganyika'), H. G. 4 (Valencia × G. H. 1 × Tennesse white).		

14.	**Til** (*Sesamum indicum* L.)	T. 4.	
15.	**Bhindi** (*Abelmoschus esculentus* Moench)	Safal Pusa Sawani (Pusa Makhamali × W Bengal Local).	
16.	**Tomato** (*Lycopersicum esculentum* Mill.)	Pusa Ruby (Sioux × Meeruti), S. M 6, Pusa Early Dwarf (Meeruti × Red cloud).	Pusa Red Plum *Lycopersicum esculentum* × *Lycopersicum pimpinellifolium.*
17.	**Pea** (*Pisum sativum* L.)	T. 56, T. 61, Early December (T. 9× Early Badger).	
18	**Gram** (*Cicer arietinum* L.)	C. 235, C. 1234, C 104 (Pb. 7× Rabat).	
19.	**Mung** (*Phaseolus aureus* R.)	K. 5 (K 4× M. P. Variety), T. 2 (T. 1 × Cul No. 4425-2), T. 44 (T 1 × T 49), T. 51 (Cul. No. 4465-4; Cult No 4974-3).	

(contd)

S. No.	Crop	Varieties of intervarietal origin	Varieties of interspecific origin	Intergeneric crosses & varieties
20.	**Arhar** (*Cajanus indicus* S.)	T. 21 (T. 1 × Strain No. 190).		
21.	**Papawa** (*Carica papaya* L.)	Co. 1.		
22.	**Grape** (*Vitis vinifera* L.)	Selection Nos. 7 and 94.		
23.	**Mango** (*Mangifera indica* L.)	Mahmud Bhahar, Probha Shankar.		
24.	**Anjan Grass**			Pusa Giant Anjan (*Cenchrus ciliaris* × *Pennisetum ciliaris*)

ADVANTAGES

(1) **Creation of heritable variation**—The crossing of unlike individuals gives rise to entirely new plants showing variations in their characters as compared to their parents. This variation is not due to creation of any genes but simply due to Mendelian recombination of the genes already present in the population. Such variations are heritable and source of evolution in plant kingdom.

(2) **Production of superior varieties**—Most of the economic characters of crop-plants result from interactions of many genes scattered over several chromosomes in different plants. *Hybridization brings all these useful factors together and concentrates them into a single variety.* Thus a variety possessing all the desirable characters such as high yield, good quality, resistance to diseases, insects, drought, etc., is produced. Secondly, the *varieties suited to every condition and need of man can be evolved.* Thirdly, *the varieties produced by hybridization are more vigorous* exhibiting hybrid vigour.

DISADVANTAGES

(1) **Tedious, time-consuming and expensive procedure**—Usually hundreds of crosses are made before obtaining an individual possessing the desired combination of characters. If only one or two characters are required to be brought into a variety, the task is much less difficult. If, on the other hand, more characters are involved the more difficult is the task in bringing the correct combination in any given individual plant. The crossing and handling of crosses need a high technical training and practical experience. Besides hard labour and cautious handling of hybrid material, a minimum period of fifteen years is consumed in producing a new variety by this procedure. Further, the continuous and constant vigilance is to be paid every year for maintaining the purity of variety, producing its seeds and distributing to farmers freshly.

Hence, hybridization is a painstaking task and when carried out extensively, it is time-consuming and, therefore, most expensive among all the breeding procedures. Keeping this in mind,

it is perhaps not difficult to understand why a variety superior for all characters has not been developed so far.

(2) **Hybrid sterility**—Sterility is the main handicap in achievements to be made by hybridization. It is more or less absolute in wide crosses and comparatively very less in intervarietal crosses.

(3) **Technical procedure**—Hybridization, being highly technical and complicated, can only be adopted by experienced plant breeders and can not be advised to farmers for adoption because the farmers accept only the achievement and not the experiments.

COMPARISON AMONG DIFFERENT BREEDING METHODS

The different breeding procedures are summarized below for having a comparative idea of different steps and time normally taken for evolving the improved varieties by each :

Table 9. Summary of different methods of crop improvement

Year	Hybridization	Pure-line selection	Mass selection
1.	Selection of parents	Single plant selection	Mass selection of plants
2.	Crossing	Row test or replicated row test	Preliminary yield trial
3.	F_1 generation	Seed multiplication	Main yield trial
4.	F_2 generation	Preliminary yield trial	Main yield trial
5.	F_3 generation	Main yield trial	Main yield trial
6.	Progeny row or Family block trial	Main yield trial	Yield trials on cultivators' fields
7.	Seed multiplication	Main yield trial	Yield trials on cultivators' fields

8. Preliminary yield trial	Trials on cultivators' fields	Yield trials on cultivators' fields
9. Main yield trial	Trials on cultivators' fields	Improved seed
10. Main yield trial	Trials on cultivators' fields	...
11. Main yield trial	Improved variety	...
12. Trials on cultivators' fields	...	...
13. Trials on cultivators' fields	...	...
14. Trials on cultivators' fields	...	...
15. Improved strain	...	...

QUESTIONS

1. Define the term 'hybridization' and state its objects of application.
2. In which type of crops and when is the hybridization used?
3. What are different types of hybridization on the basis of relationship between the parents involved in it? Give the example of each type.
4. For what work the following scientists are famous in plant breeding:

   Camerarius   Fairchild
   Cotton Mather   Kolreuter
5. Why is the hybrid from the cross of sweet william and carnation known as 'Fairchild's mule'?
6. Enumerate the pre-requisites of hybridization procedure and give a short account of each.
7. How many steps are involved in the hybridization procedure? Describe only two most important in detail.
8. Define 'selfing' and why is it done?
9. How is selfing done in self as well as cross-pollinated crops? Describe only in brief with precautions.

10. What are the effects of inbreeding in different type of crops?
11. Define the term 'inbred' and why are the inbreds needed in the hybridization ?
12. What is the genetical constitution of the inbreds and why are they not released directly as the improved varieties in the cross-pollinated crops ?
13. Give the definition of emasculation and mention its main purpose.
14. At what time and stage the emasculaticn is done in the plants and describe its different ways in which it is carried out in the various crops ?
15. When and why is bagging done in the hybridization ?
16 Define the term 'crossing' and discuss its operation in different crops.
17. What is the necessity of labelling and when is it done? Described how is it done and illustrate with the help of diagram ?
18. What are hybrids and how they all look in F_1 and why ?
19. Describe the pedigree method briefly and give the name of crops in which it is used.
20. State the advantages and disadvantages of pedigree method. Describe only in brief.
21. Make an exhaustive comparison between pedigree method and bulk method and also list their differences.
22. Define the 'backcross' and state when is it used? Describe its procedure briefly.
23 What is 'multiple cross' and when is it used in the self-pollinated crops ?
24. Name the different types of crosses made in the cross-pollinated crops and give a brief account of each with features.
25 Define the 'single cross'. Mention the formula used for calculating the number of single crosses made out of various inbreds. Suppose eight inbreds are involved, how many single crosses will be made from them ?
26. What are the characteristics of hybrids obtained from single cross ? Why are the single crosses undesirable commercially and where are they desirable ?

27. Define 'three-way cross' and discuss its merits and demerits.
28. Define 'double cross' and describe how is it produced.
29. Give the formula used for finding out the number of double crosses from different number of inbreds. Calcu-late all the possible double crosses. Can they be made out of eight inbreds ?
30. Define top-cross and when is it used ?
31. Mention the difficulties faced and precautions taken during the hybridization work.
32 What is the effect of hybridization in crops ?
33. Describe the advantages and disadvantages of hybridization.
34. 'No new genes are produced by hybridization' then how is the improvement sought by it in crops ? What is the difference between the improvements obtained by selection and by hybridization ?
35 Give the way of origin and parents of the following varieties with their crops :
Pusa Red Plum, C.281, R. S. 31-1, Kufri Kuber, Early December and Pusa Giant Napier.
36. Differentiate between the following :
Selfing and self-pollination
Inbreeding and selfing
Crossing and cross-pollination
Double cross and commercial hybrid maize
Top cross and three-way cross.

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CHAPTER 8

HETEROSIS OR HYBRID VIGOUR

When two homozygous inbreds of genetically unlike constitutions are crossed together, the resulting hybrids obtained from the crossed seeds are usually vigorous, productive, sturdier and taller than either parents. This increased productivity or superiority of the hybrids over the parents is known as **heterosis** or **hybrid vigour** and is defined as follows :

Heterosis or hybrid vigour is the increased vigour, growth, yield or function of a hybrid, over the parents, resulting from the crossing of genetically unlike organisms.

It is quite evident that the crossing results in hybrid vigour and the inbreeding into depression and, therefore, the hybrid vigour is just reverse to the inbreeding effects.

It is not a newly discovered phenomenon but has been known since the art of hybridization came into existence Kolreuter (1763) and other early hybridizers were quite aware of its existence in plants. Mendel (1865) observed its menifestation in his pea crosses Charles Darwin (1876) had also concluded that the inbreeding in plants results in the deterioration of vigour and the crossing in hybrid vigour. He further realised that the hybrid vigour results, not merely from crossing, but from the union of unlike germplasms. Dr G H Shull coined and proposed the term 'heterosis' for the first time in 1914 and he derived it from the Greek words *heteros* means



Fig 28
George H Shull (1874-1954), father of hybrid corn who coined the term 'heterosis' in 1914

different and *osis* means condition. Heterosis, therefore, literally means a different condition, i.e., different from their parents. Usually the terms heterosis and hybrid vigour are used synonymously. Poweri (1944 and 1945) considers that the crossing, however, may result in either vigourous or weak hybrids as compared to parental inbreds and this is actual heterosis. According to this view heterosis and hybrid vigour are not equivalent terms, but the hybrid vigour refers to only the increased vigour and size while heterosis to both increased vigour and weakness of hybrids. Heterosis, therefore, may be of two types, **positive** or *plus* i.e., **beneficial heterosis** and **negative** or *minus* i.e., **nonbeneficial heterosis** Whaley (1944) suggested that it would be more appropriate to term the developed superiority of the hybrids as hybrid vigour and to refer to the mechanism by which this superiority is developed as heterosis. Hayes, Immer and Smith (1955) are also of opinion that the use of heterosis and hybrid vigour as synonyms is highly desirable on the basis of their long usage. Whatever may be the controversy over the equivalence of heterosis and hybrid vigour, both have been used interchangeably ever since and still the same state of condition is in vogue practically.

EFFECTS OF HYBRID VIGOUR

Heterosis does not affect an individual as a whole but only its separate parts such as root in carrot; tuber in potato and knol-khol; corm in colocasia; hypocotyl in turnip, beet and radish; leaf in cabbage, spinach and lettuce; flower in cauliflower, fruit in pea, lobia, *bhindi*, brinjal and cucurbits; kernels in maize; ears in cereals; and the seeds in green peas and *Dolichos lablab*.

The effects of heterosis in these parts can be expressed in three ways:

1. **Quantitative effects**—There is an increase in size and number of quantitative characters like yield, fruit, vegetative parts, etc., due to a greater number of cells resulting from a faster cell division and cell activities. This improves the general well-being of an organism similar to that resulting from placing in a more favourable environment.

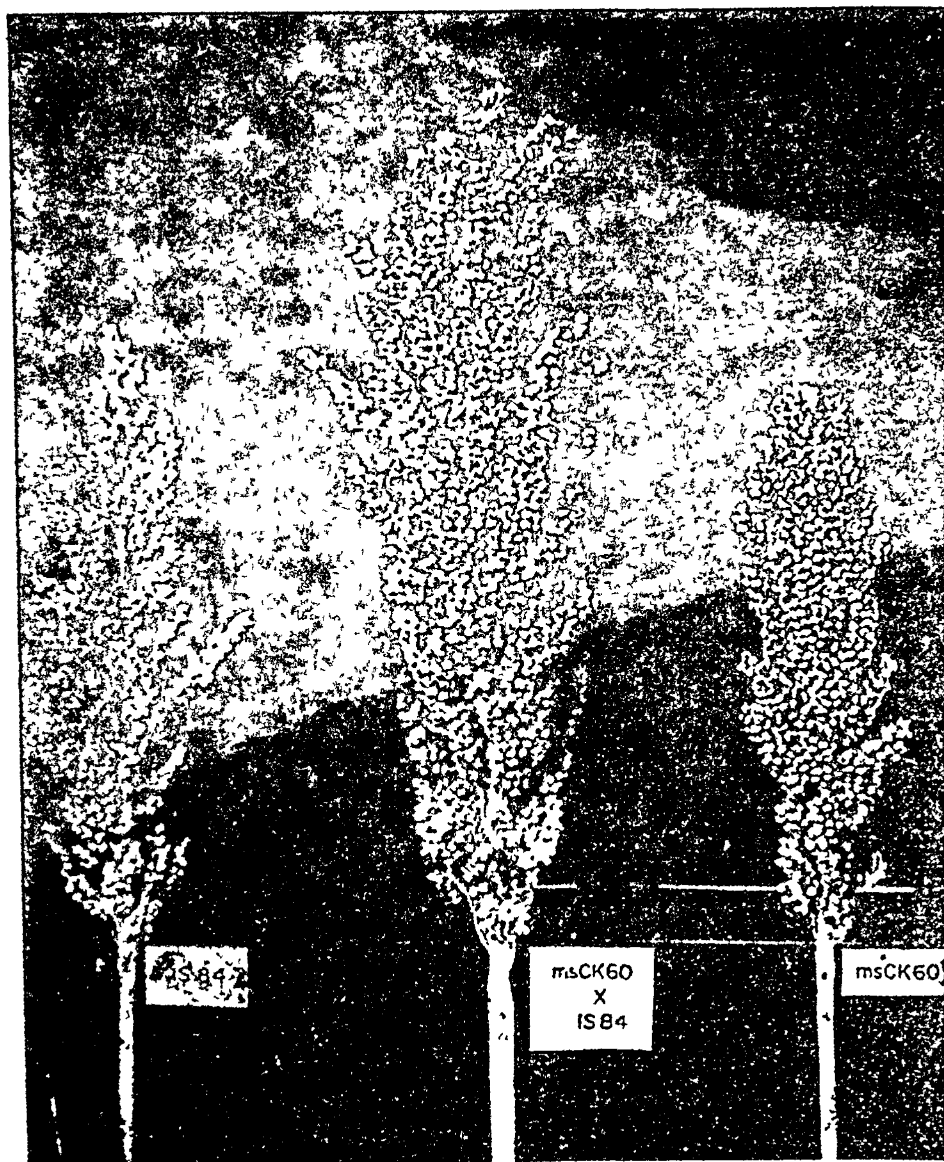


Fig. 29

Hybrid vigour in *jowar* : CSH-1 hybrid Variety in the Center and its parents on both sides (*By Courtesy of Dr. N G P. Rao*).

2. **Biological effects**—There is an increase in biological efficiency of an organism such as reproductiveness and survival ability exhibited in economic characters. Some confusion has crept in due to no clear-cut distinguishing line between these two different manifestations of heterosis.

3. **Physiological effects**—Effects of the heterosis are also manifested in many physiological traits like adaptability, disease and insect resistance, earliness, etc.

All these effects of heterosis can be represented more categorily as follows :

1. Greater height, weight, size and number of the different parts of the plant.
2. Increase in yield and growth.
3. Greater fertility and viability.
4. More efficient seed germination.
5. Longevity, i. e., greater length of life than their parents.
6. Earlier flowering and maturity.
7. The increased resistance to diseases, insects and drought, and the lessened susceptibility to adverse environmental conditions.
8. Many other good manifestations.

In addition to the better heterotic effects, there may also be reverse effects in normal set-up of the organism, in other words, **negative heterosis**. This effect is rarely found in cultivated plants and domesticated animals (Gowen, 1952).

The extent of heterosis expressed in hybrid depends upon the origin, relationship and compatibility between the inbreds involved. The hybrids from the crosses between distantly related inbreds or inbreds of more genetic diversity presumably exhibit more hybrid vigour than those from more closely related parents or parents of same and similar origin. According to East and Hayes (1912) and East (1916), the amount of hybrid vigour expressed in the F_1 hybrid plant is roughly proportional to the genetic diversity in between two parental inbreds, provided the hybrid develops normally. East (1916) indicated that the interspecific crosses exhibit more hybrid vigour than the intraspecific crosses. Further, he observed that the certain genes exert greater effects on heterosis

than others and also that a particular gene may have more effects in some combinations than others. Particular combinations of small number of genes may also have special effects on heterosis (Hill and Hill, 1955).

Heterosis is not equal in all crosses, but in some little improvement is obtained whereas in others major differences are observed. Heterotic effects are also not fixable and lasting, but decrease in F_2 and go on diminishing in each succeeding generation due to Mendelian segregation of traits.

Sometimes the hybrid vigour, in spite of resulting from crossing, may also result from other sources. On the basis of source of increased vigour, heterosis is divided into three types

(1) **Balanced heterosis**—It is the true heterosis with which we are concerned here and is produced by crossing

(2) **Mutational heterosis**—Hybrid vigour may also be created by mutations in organisms which is termed as mutational heterosis. Mutations are seldom beneficial and, therefore, the mutational heterosis is of rare importance in comparison to true heterosis.

(3) **Pseudoheterosis**—Sometimes due to more favourable environment and better cultural practices, the increased growth and vegetative luxuriance are observed in plants which is referred as pseudoheterosis. This is a temporary vigour of an accidental occurrence and, therefore, cannot be utilised in practical plant improvement.

CAUSES OF HETEROSIS

The phenomenon of hybrid vigour can be explained on the basis of genetical and physiological causes.

Genetical causes

Two genetical hypotheses, each backed by experimental evidences, have been put forward to explain the cause of hybrid vigour and they are :

(1) **Dominance hypothesis** —Bruce got some initiation from Davenport's ideas (1908) and proposed this hypothesis for the first time in 1910 *which is based on the assumption that hybrid vigour results from bringing together the maximum number of dominant favourable genes in F_1 hybrids. According to this concept, the heterosis is*

conditioned by a large number of hereditary factors in which the favourable genes are dominant and unfavourables are recessive. The inbreds differ genetically from each other and, therefore, one inbred may have a certain set of dominant genes and another may have another set of dominant genes. *The crossing may bring all these dominant genes together into one hybrid from different inbreds giving rise to hybrid vigour.* For simplicity, suppose two inbreds A and B are crossed to produce F_1 hybrids, whereas A has got the genotype AA bb cc DD EE and B has got the genotype aa BB CC dd ee, in which A, B, C, D, and E are dominant genes each contributing 5 cms. towards the height of hybrid. In the absence of dominants, each recessive gene contributes 1 cm. towards height. Here only one pair of chromosomes is taken and others are discarded for simplification. The genotype of F_1 hybrid with parents is shown below :

Inbred A	X	Inbred B
AA bb cc DD EE		aa BB CC dd ee
Dominant genes=A+D+E =3×5=15 cms.		Dominant genes=B+C =2×5=10 cms.
Recessive genes=b+c =2 cms.		Recessive genes=a+d+e =3 cms.
Total height=15+2 =17 cms.	V	Total height=10+3 =13 cms

F_1 hybrid

Aa Bb Cc Dd Ee

Dominant genes=A+B+C+D+E=5×5=25 cms.

Similar explanation may also be extended for all other chromosomes and numerous gene pairs in any plant species.

In the above cross, the heights of two inbreds are 17 cms. and 13 cms. respectively, while that of hybrid from them is 25 cms. This illustrates that the hybrid has got more favourable dominant genes and for this reason, it contains more vigour greater size and increased yield than either of its parents. If favourable combination of genes is possible, the hybrids may even exceed the mean of the parents in these respects.

Bruce (1910) in his original experiments also proved mathematically that the total number of dominant genes were greater

in a hybrid population than in either parental populations. The exact procedure to present mathematically here is beyond the scope of this text and, therefore, the readers are advised to consult "Heterosis" by Gowen for details.

Objections

(i) *Why not true breeding homozygous lines are obtained in succeeding generations*—If this hypothesis is correct, it should be possible to obtain at least some plants homozygous for all the dominant genes in F_3 generation raised by inbreeding the F_1. They must be like F_1 population in vigour and breed true for hybrid vigour in succeeding generations. But, as already stated above under effects, one of the peculiarities of hybrid vigour is that it is an unfixable trait and decreases in each subsequent generation until and unless maintained artificially

(ii) *Why heterotic characters are symmetrically distributed rather than skewed*—If heterosis is due to dominance of independent factors, the F_1 distribution curve should be skewed rather than symmetrical because the dominant and recessive phenotypes or loci would be distributed according to the binomial expansion $(3/4+1/4)_n$, where n is the number of factors involved.

These objections were removed completely by Jones (1917) in his modified theory entitled **'Dominance of Linked Genes Hypothesis'**. He pointed out that a large number of dominant genes distributed over different chromosomes are involved in production of hybrid vigour. The favourable and unfavourable genes may be linked together due to which true breeding homozygous plant and skew distribution of F_2 loci cannot be obtained. Later, Collins (1921) showed that even with a large numbe of factors, regardless of linkage, the skew distirbution disappears in F_2 and the chances of obtaining a completely homozygous plant are remote. This hypothesis of Jones is most widely accepted, because it provides the best explanation underlying the mechanism of hybrid vigour.



Fig. 30

Donald F Jones who profounded *'The Dominance of Linked Genes Hypothesis'* as a genetical cause of heterosis in 1917

(2) **Overdominance hypothesis**—The concept of thishypothesis was given independently by Shull (1908) and East (1908) on the supposition that heterozygote is superior to either homozygotes and the hybrid vigour increases in proportion to the amount of heterozygosity. To this idea, various names had been given from time to time as *superdominance* by Fisher (1930), *interaction of alleles at a single locus* by East (1936), *overdominance* by Hull (1945), etc. However, the term '*overdominance*' is most commonly used among all.

In more simplified terms, this hypothesis assumes that heterozygous gene condition $a_1 a_2$ is superior to either of the homozygous gene combination $a_1 a_1$ or $a_2 a_2$. The a_1 and a_2 perform different functions and the product produced by their combination is more vigorous than the single product produced by either allele in the homozygous condition. East (1936) extended this idea further by assuming a series of alleles a_1, a_2, a_3, a_4, ...of gradually increasing divergence of function. Heterozygotes were supposed to become more and more efficient as their alleles differed more and more in function which were genetically represented as $a_1 a_2 < a_1 a_3 < a_1 a_4$ and so forth. If, in spite of alleles, two inbreds homozygous for different genes are crossed, the hybrid is much more vigorous than either lines. Hence, the cross AA bb cc DD ee × aa BB CC dd EE would produce a hybrid Aa Bb Cc Dd Ee which is heterozygous for all the genes always exhibiting hybrid vigour. *This theory, then, suggests that there is something inherent in the heterozygous condition that brings about hybrid vigour and thus greater the number of heterozygous alleles greater will be the hybrid vigour in the organism.*

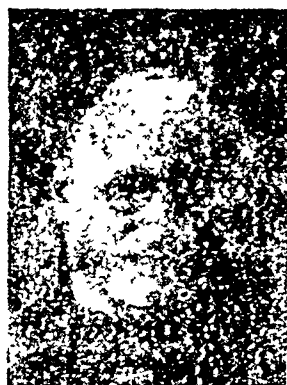


Fig. 31
East, E M., An American Plant Breeder, who proposed the "*Overdominance hypothesis*" as a genetical explanation of heterosis in 1908

Occasionally, there is a plea that if the cause of heterosis is heterozygosity, it means homozygosity and inbreeding lead to weakness. But the self-pollinated crops such as wheat, barley,

rice, etc. which are normally homozygous, do not exhibit any weakness and secondly, the inbreeding in them does not show any loss of vigour as in case of maize. The explanation may be a simple one that due to continuous natural inbreeding in them the recessive deleterious genes hidden in heterozygous condition might have been made homozygous soon after their origin and eliminated in natural course of selection. Accordingly, these species became adapted to homozygosity and developed a genetic organization that Mather (1943) calls as *homozygous balance*. One of the attributes of this balance is that the inbreeding leads to no diminution in vigour and at the same time F_1 hybrids between different lines are fully vigorous and display heterosis.

The relative importance of these two mechanisms of heterosis, i.e., dominance and overdominance remains yet to be determined. In most of the cases both the hypotheses lead to the same results. In either case, there is an increase in hybrid vigour on crossing and a decrease in it on inbreeding.

Physiological causes

(1) **Greater initial capital hypothesis**—Ashby (1930) studied the physiology of inbreds and hybrids of maize and tomato, and concluded that the hybrid vigour is due to an increased initial embryo size which he termed as 'Greater initial capital'. The validity of this cause, however, has been disputed by many other workers working on the same plants. East (1936) and Wang (1947) also supported this hypothesis and reported that the increase in endosperm and embryo size is one of the causes of heterosis. Whaley (1950) found that the maize hybrids have more efficient protoplasm and more green and dry weight than the inbreds.

(2) **Cytoplasmic-nuclear reaction**—Michaelis, Shull, Lewis and others suggested that physiological cause of hybrid vigour is the interaction of cytoplasmic and nuclear systems.

Whatever may be the cause, genetical or physiological, the hybrid vigour is a well-known phenomenon, its effects are well established and achievements are spectacular.

BREEDING METHODS AND TECHNIQUES

The methods of heterosis breeding are same as those of hybridization described in chapter 7. Here only a special mention is made to **polycross** method which was suggested by Tysdal, *et al.* (1942) and is being used extensively to-day with perennial leguminous forage crops that are normally cross-pollinated like lucerne. This method consists in planting the vegetatively multiplied clones of several self-sterile plants in a polycross nursery and allowing each clone to be randomly pollinated by the other clones.

Heterosis breeding involves emasculation, pollination and bagging. Among all the three, the emasculation, which too by hand, is most expensive and cumbersome. Hand emasculation and pollination are economical only in those crops where each fruit produces a large amount of seeds and a limited quantity of seeds is required for raising the crop such as in tomato, brinjal, cucumber, pumpkin, etc. On the contrary, such an expensive procedure is disadvantageous in crops where each hand-pollination produces a very little quantity of seed as in cabbage, knol-khol, cauliflower, etc., and the floral parts can not be handled easily as in onion and carrot.

Keeping into mind the above difficulty from farmers' purchasing capacity point of view and depending upon the nature of pollination, floral structure, male-sterility and the number of seeds per fruit, **the different techniques of emasculation and crossing commonly used in different crops are listed below :**

(1) **Hand-emasculation and hand-pollination**—This technique is practised in plants having bisexual flowers where each fruit produces a larger number of seeds with single pollination like tomato, brinjal and lady's finger In wheat and barley also this method is used because once a superior hybrid is obtained, though costly, can be easily maintained without incurring the expenses for seed multiplication in subsequent years.

(2) **Hot water emasculation and hand-pollination**--This is carried out in crops like paddy and sorghum where hand emas-

culation is time-consuming. The panicles to be emasculated are dipped in hot water of desired temperature for a particular time. The temperature and time are so adjusted for a particular crop that they only make the male parts functionless without any adverse effect on the female The crossing is done by either bagging the male and female together or dusting the female with pollens of desired male.

(3) **Male-sterility and hand-pollination**—Presence of male-sterility, may be due to any cause, eliminates the emasculation which is most laborious operation in breeding procedures. The pollination can be then carried out either by hand or by 'electric pollinator' suggested by Cottrell-Dormer (1945) in plants like tomatoes. Electricity in this is generated by a battery of three cells (4.5 volts). The instrument contains a fine wire loop which is made to vibrate within a pollen collecting chamber. By bringing the stamens of the flower in the loop and causing the later to vibrate, the pollens are readily shaken from the another into the chamber. The pollination is also carried out in the same way.

(4) **Hand-pollination without emasculation or Emasculation by removal of female flowers and free-pollination**—These practices are followed in monoecious plants where male and female are separate on the same plant, such as maize, cucumber, squash and melons. In them there is no need of emasculation but the pollination is to be carried out by hand. Even the hand-pollination can be avoided by planting the male and female parents in alternate rows and removing the male flowers from female parent before their opening so that there may be pollination in desired way automatically. At the time of harvesting, the fruits of female and male varieties are picked up separately whereas fruits of female are hybrid and those of male are selfed. This technique is being used on commercial scale for production of hybrid seed in these crops According to Walkof and Nuttal (1955) in Canada, the hybrid seed in these plants is produced similarly by planting two rows of female to one row of male alternately. Male flowers of the female parent are removed as soon as they show yellow colour continuously for five weeks. Pollina-

tion is carried out by insects such as bees. This method of emasculation and crossing is termed as **"Crossing Block Method".**

(5) **Emasculation by removal of male plants and wind-pollination**—In dioecious species, **i.e.**, having male and female flowers separate on separate plants such as spinach and asparagus, the male flowers usually flowering earlier are removed from the variety used as female parent. The male variety should be sown by the side of female so that the pollination can take place automatically through the desired agency; but at the time of harvesting both should be harvested separately in which the produce of female variety would be the needed hybrid seed.

(6) **No emasculation and free-pollination**—This technique is practically adopted in those cross-pollinated crops where the emasculation is either tough as in carrot and onion or easier but each hand-pollination produces only a small quantity of seeds as in radish and cabbage. Sometimes, the presence of cytoplasmic sterility in them also eliminates the emasculation.

(7) **Emasculation by chemical suppression of male flowers and free-pollination**—Wittwer and Hillyer (1954) observed that spraying dilute solutions of maleic hydrazide (MH) or B-naphthalene acetic acid (100 p. p. m.) on young seedlings of *Cucumis pepo* suppressed the formation of male flowers. Hensz and Mohr (1959) also reported that sodium alpha and beta-dichloroisobutyrate (FW-450) checked the opening of mature male buds in watermelon without affecting female fertility. In this it may be possible to avoid the emasculation in female parent for producing F_1 hybrids.

ACHIEVEMENTS

Hybrid vigour has been exploited both in plants and animals and is being utilised on commercial scale. In plants, it has been used in the improvement of maize, sorghum, *bajra*, paddy, wheat, cotton, tobacco, sugarcane, potato, gram, radish, coconut, brinjal, lady's finger, onion, cabbage, tomato, sugarbeets,

squash, cucumber, forage crops and grasses, ornamentals, fruit and forest trees, fungus like *Penicillium* and other useful plants. Hybrid vigour has showed an increase in the yield as 50% in sugarcane, 30% in tobacco, 30-60% in *bajra* and radish, 40-45% in brinjal and has improved the fibre quality in cotton, rust-resistance in wheat, virus-resistance in *bhindi*, production of penicillin in *Penicillium*, etc. More exactly it can be said that hybrid vigour has ameliorated the crops in all aspects.

Hybrid vigour has also been exploited in animals such as cattle, poultry, pigs, beef-cattle and silkworms The mule, hybrid from a cross between jack *(Equus hemious)* and mare *(Equus equus)*, has been known since ancient times for its well-known qualities of strength and stubbornness. The hybrids, from the cross between Red Sindhi breed of Indian cattle and Jersey breed of America, contain 30% more butter fat per cow and are heat resistant. Similarly the more egg laying in hen, increased pork yield in pigs and greater silk production in silkworms are the few miraculous achievements of hybrid vigour in animals

However, the careful exploitation of hybrid vigour in cultivated plants and domestic animals may increase the production of food and fibre directly resulting in better nourished human race and more prosperous agriculture.

UTILIZATION AND LIMITATIONS

Heterosis has been of immense pratical utility in the improvement of all types of crops, but the task of its utilization is full of difficulties which are enumerated briefly as follows :

1. **Self-pollinated crops and hybrid vigour**—The utilization of hybrid vigour on commercial scale requires the production of hybrid seed in sufficient quantity to meet the demand of farmers. In self-pollinated crops, the hand-emasculation and hand-pollination are usually practised which are tedious and costly operations. This difficulty is again made more severe where only few seeds are produced with each act of hand-pollination. This difficulty of little hybrid seed production with high expenditure practically prohibits the utilization of hybrid

vigour in such crops. On account of this fact, very little improvement has been achieved by heterosis in self-pollinated in comparison to cross-pollinated crops. But this difficulty has been now overcome by the development of easier and cheaper genetical and chemical methods of emasculation (Pal and Sikka, 1956) for most of the perfect-flowered plants.

2. **Cross-pollinated crops and hybrid vigour**—It has been utilized spectacularly in these crops, but difficulty is faced in maintaining the hybrid vigour at the same level from generation to generation because it decreases rapidly in F_2 and each succeeding generation due to cross-pollination and Mendelian segregation. The cultivators can not, therefore, be advised to save the seeds from hybrid crop for next year. In order to overcome this difficulty, the parental inbreds are maintained, single-crosses are made, if needed double-crosses are produced and distributed to farmers every year freshly.

3. **Vegetatively propagated crops and hybrid vigour**—Although the difficulty in emasculation and crossing is faced, which in turn is compensated by easier multiplication and maintenance of hybrids. In such crops, once obtained desirable hybrid can easily be maintained and multiplied by vegetative propagation until and unless there are disturbances due to somatic mutations.

CONCLUSION

Hybrid vigour is now an universally accepted practical phenomenon evolved by the combined application of genetics and plant breeding. Heterosis, which is a quick, cheap and easy method of increasing food production (Pal and Sikka, 1956), is being practised in all crops of economic value all over the world. This, in future, may eventually produce such crop varieties which far transcend the present crop production and thus solving many human problems.

QUESTIONS

1. What is 'heterosis' ? Who coined it for the first time and in which year ?

2. In what different forms the heterosis is manifested in plants ? Describe categorily.
3. What are different types of heterosis and differentiate between the balanced and pseudoheterosis ? With which type we are mainly concerned in plant breeding ?
4. In general, what genetical theories have been put forth to explain the cause of heterosis ? State the concept of each theory precisely. Which one is more acceptable now-a-days and why ?
5. Explain, how is it possible that the both hypotheses, i.e., dominance and overdominance lead to the same results ?
6. Outcrossing leads to hybrid vigour and inbreeding to loss of vigour. Is it so always ? Give reasons in support of your opinion.
7. Inbreeding was done simultaneously in two separate crops. It was repeated for five or six generations in them and effects were observed. In the plants of one crops loss of vigour was seen but in the plants of another crop no such effect was obtained. How do you account for it ?
8. Usually inbreeding has no effect in wheat which is a self-pollinated crop. Explain why ?
9. Describe the 'homozygous balance' and what does it explain in hybrid vigour ? Who advised it for the first time and in which year ?
10. What are the limitations in obtaining the hvbrid vigour in different types of crops ?
11. Very less improvement has been achieved by heterosis in self-pollinated crops in comparison to cross-pollinated crops. Explain the practical handicap behind it ? Is this state of condition prevailing still ? Why ?
12. Heterotic effects decrease in F_2 and go on diminishing in each succeeding generation. Give its genetical cause for clarification.
13. Why the farmers, instead of being allowed to use the seed from previous year's crop, are distributed fresh seed of hybrid maize every year ? Discuss.

14. State the advantage of once obtained hybrid vigour in vegetatively propagated crops over the sexually reproduced crops.
15. Cite the names of some crops in which hybrid vigour has been utilized practically in India.
16. For what contributions, the following scientists are popular in the field of plant breeding :

Shull, G. H.,	East	Ashby
Whaley	Bruce	Tysdal
Gowen	Jones	

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CHAPTER 9

PLANT INTRODUCTION AND ACCLIMATIZATION

'Plant introduction and acclimatization' is the easiest and most rapid method of crop improvement in which the acclimatization follows the introduction and both the processes go side by side. They can be defined separately as follows :

Plant introduction is the process of introducing plants from their growing locality to a new locality.

Thus, in this process the plants are transferred from one place to another having a different climate.

Acclimatization is the adaptation or adjustment of an individual plant or a population of plants under the changed climate for a number of generations.

Thus, acclimatization is a sort of natural selection operating into the introduced plant material.

The plants may be introduced either from the country of another continent (**intercontinental plant introduction**) such as *ridley* wheat variety from Australia; from another country within the same continent (**intracontinental or intercountries plant introduction**) such as litchi and loquat from China, from another state within the same country (**interstate plant introduction**) such as N P. wheat varieties from Delhi, into different states within the country or from another district within the same state (**intrastate or interdistrict plant introduction**) such as distribution of state recommended varieties of different crops from one district to another within the same state for general cultivation. Any plant material, therefore, brought from another place, may be within or outside the country, must be termed as introduced mate-

rial and method as plant introduction; but by plant introduction *we usually mean the introductions of the plants from places outside the country, may be of same or another continent.*

PURPOSES

Purposes of introducing plant material from outside are four as listed below :

(1) **For use in agriculture, forestry and industry**—Many cereal, millet, sugar, forest, industrial and medicinal crops are the results of introductions from outside in the past and have led to the prosperity of country.

(2) **For studying the origin, distribution, classification and evolution of the plants**—The plants are introduced to maintain their permanent living collections in botanical gardens, research farms, herberia, arboreta and museums of the country where their detailed study furnishes valuable scientific data and information which aid considerably in tracing out the origin, classification and evolution of different crop plants. Vavilov's Eight Centers of Plants' Origin were established with the help of such plant collections gathered by Russian scientists from all over the world.

(3) **For fulfilment of aesthetic interest**—The plants and shrubs, specially the ornamentals, are introduced to enrich and adorn the gardens, parks, buildings and bungalows so that the interest or fancy for uncommon and bizzare forms may be fulfilled. At present the beautiful gardens and parks in every country are due to plantation and growth of such introduced plant wealth which is indeed the great source of entertainment, drawings, paintings and imaginations to fatigued persons, designers, artists and poets

(4) **For the genetical improvement of economical crops**-Crop plants or their strains possessing superior qualities are introduced and used as parental material in crossing so that their useful economic characters can be incorporated in local materials for their genetical improvement.

HISTORY AND ORGANIZATION

In olden times the plant introductions in India were haphazard

and by whim or chance. The missionaries, traders, travellers, adventurers, explorers, priests, pilgrims, politicians, colonists, scientists and several other agencies played an important role in introducing new plants in the remote past from distant countries into India.

The Portuguese who settled in Goa in 1510, are reported to be responsible for introduction of several crops such as maize, potato, chillies, groundnut, sweet-potato, guava, papaya, pineapple, cashew-nut and some others in India. The East India Company also took keen interest in introduction of new plants and plant strains and established the Calcutta Botancial Garden in 1781.

These uncontrolled plant introductions in the past are reported to be responsible for the introduction of new harmful insect pests, diseases and weeds along with the introduced material.

Scientific Approach to Plant Introduction

Scattered attempts—With the establishment of Central and State Agriculture Departments in the country, in the beginning of present century, attention was paid to the introduction and improvement of agricultural and horticultural crops. Scattered attempts were made by various agencies in the agriculture departments to introduce foreign material into the country (Singh 1963). These efforts, no doubt slow and scattered, resulted in amazing diversity of economic plants

Systematic attempts—The planned plant introduction was started when the Indian Council of Agricultural Research sanctioned a small Scheme of Plant Introduction at I.A.R.I., in 1946. This Scheme was expanded under the Second Five Year Plan into a Plant Introduction and Exploration Organization. Simultaneously the organization was given the status of a Division at I.A.R.I., New Delhi, under the Third Five Year Plan. This new Division of Plant Introduction, headed by Dr. H. B. Singh, is undertaking whole work of introducing plant material relating to agricultural and horticultural crops

Present Organization

The introduction of plant material in India at present is carried out by the following agencies

1. **Plant Introduction Division of I.A.R.I**—This new Division introduces the useful plant material of agricultural and horticultural importance.

2. **Forest Research Institute, Dehra Dun**—The Plant Introduction Organization, recently set up at the Forest Research Institute, Dehra Dun, looks after the introduction and testing of trees and plants of forest interest and importance.

3. **Botanical Survey of India**—It was established in 1890 and entrusted with the introduction of plant material of medicinal and botanical interest.

The work of all these three agencies is co-ordinated by the Plant Introduction Co-ordination Committee of I.C.A.R. of which the Agricultural Commissioner is the chairman.

4. There are some **Central Research Institutes and Committees** for important commercial commodities such as tea, coffee, sugarcane, potato, tobacco, cotton, coconut, oilseeds, etc., which also introduce the material of the particular commodity with which they are concerned.

5. Besides these, there are individual teachers and plant scientists in the Universities, Gardens and Agricultural Departments who also play an important role in introducing the plants from outside by personal approach. But such attempts are inadequate and restricted in scope The work of these individual workers is not co-ordinated by any Co-ordination Committee and, therefore, is of scattered nature.

Functions of plant introduction agencies—The functions of all the agencies, concerned with the work of plant introduction, are four as follows :

1. Introduction of plant material from different sources within and outside the country.
2. Plant exploration expeditions within and without the country
3. Assessment and utilization of the introduced plant material.
4. Maintenance of introductions in living as well as in specimen forms in gardens, farms, herberia and museums

PROCEDURE

Procurement of the plant material from the places within the country is very convenient but from abroad is somewhat cumbersome. There is a definite procedure for plant introduction from outside and its different steps with their salient features are discussed here.

Type of material to be introduced—New plant material is often needed by different disciplines of botany, such as plant breeder, agronomist, cyto-taxonomist, physiologist, geneticist, gardener, plant-geographer, etc., and therefore, the type of material to be introduced varies according to the nature of individual's requirement and interest.

The material which is not available in the locality and if available, the one superior in some desired characters to local, is introduced. In spite of all these, the material which has likelihood of satisfactory adaptation under the new environment is usually introduced. Certain plants such as potato, petunias, nasturtium, asters, snapdragon and stocks are cosmopolitan and would succeed over a wide range of latitude and climate. Polyploids and cross-pollinated crops are easily adaptable to new climate.

Both, the whole plant as well as its portions such as seeds, clonal parts, pollens and nodules can be introduced but it again depends upon .

1. *Purpose of introduction*—If introduction of plant material is made for preservation in herberia and museums, the whole plant with all its parts should be introduced so that it may exhibit all features needed in identification and classification For use in botanical gardens, the vegetative parts should be imported so that they can be easily grown and multiplied to enrich the beauty of gardens In plant breeding the type of material to be introduced depends upon the stage of breeding programme where to be utilized. Generally the seeds are introduced but, if it is simply for crossing at eleventh hour, pollen grains should be introduced so that they may be used without any delay in obtaining them by growing the crop If pollen grains due to difficulty in their preservation can not be imported, the only alternative is to introduce

seeds. For studying the modifications in characters due to change of climate, both seeds and cuttings should be introduced so that the comparison between original and newly grown plants can be made easily for morphological characters.

2. *Type of crop*—In vegetatively propagated plants the cuttings or seedlings are introduced, while in sexually reproduced crops the seeds are imported.

The introduction of new plants in form of seeds is the easiest and safest way, because they create least trouble in packing and transport and can be treated easily with chemicals in dispatching and receiving countries to prevent the dissemination of seed borne pests and diseases. The import of cuttings, tillers and other vegetative material with some attached soil is much more difficult as regards the packing and transport of material itself and greater danger of introducing the pests and diseases in material as well as soil attatched thereto.

Quantity and quality of the material to be introduced is determined by the requirements of the worker, and funds and facilities available at the time of need. However, the intoduced amount must be so much which can represent the whole plant population and particularly must be adequate to express the desired characters for which it has been introduced.

Place from where to be introduced—Before introducing the material, the soil and climatic conditions in the respective country and prevailing insect pests and diseases should be considered carefully. As far as possible the material should be introduced from the regions having similar soil, climate, and agronomical and cultural practices.

A crop material is usually introduced from the region or country where the greatest variation is found in that particular species, i.e., areas which are rich in genotypes of genetical importtance. Such range of genotypes is normally found in the following types of places :

1. The place which possesses greater variation in topograpy, soil and rainfall.
2. The place which is the centre of origin of that particular plant species.

3. The place where the needed plant species occurs both in wild as well as cultivated forms.

Now-a-days. F. A. O. is also maintaining World Catalogues of Genetic Stocks of wheat, rice and some other crops from where the needed material can be demanded at any time easily. The material from here is supplied under full precautions keeping in view the demand and interest of the workers

Ways of plant procurement—Most of the plant material is introduced deliberately for use in agriculture and industry through :

(1) Exploration expedition—An expedition, may be from any organization, is composed of a team of scientists and is sent for personal exploratory search to the unexplored areas within or outside the country where its members pick up and collect the material of their own choice.

(2) Exchange—The material under exchange is obtained from friendly countries through their organizations such as embassies, F.A O. office, U.S.A.I.D , Rockefeller Foundation, Ford Foundation, and other scientific and cooperative international societies existing inside the country.

(3) Purchase or gift—The plant material can be easily procured by correspondence with agricultural institutions, stations, departments and botanical gardens from where it can be either purchased or obtained as a gift.

Apart from these introductions by deliberate intent, occasionally plant material also comes in unsolicited way through travellers and foreign service workers which is usually of little enonomic use but more harmful to the country in the form of new pests, diseases and weeds.

Packing of material for transport—The sender first cleans and treats the seeds with fungicides to make them free from weed seeds, seed-borne diseases and other contaminations and then packs them up in his own way of convenience. Special problem arises only with transport of seeds from tropical countries where there is little or no dormant period. Techniques have been worked out for this such as the use of

charcoal packing in vacuum flasks (Whyte, 1958). The packing of living vegetative material over long distances, generally by air, involves the various methods of preserving and packing. F.A.O. has adopted 'the packing of grass tillers with their roots encased in damp cotton wool and four or five tillers packed together inside polythene bags. These have the reference numbers on labels inside and outside the bag, which is itself closed by a plug of cotton wool (Whyte, 1958)'.

Pollen grains are preserved and packed according to their behaviours for duration of viability and the temperature at which they remain viable and then these are transported in different ways. Usually the pollen grains are directly collected, stored, dessicated, packed and transported into unbreakable and heat resistant polythene tubes. Direct collection of pollens in the tubes minimizes the mixing of undesirable foreign pollens.

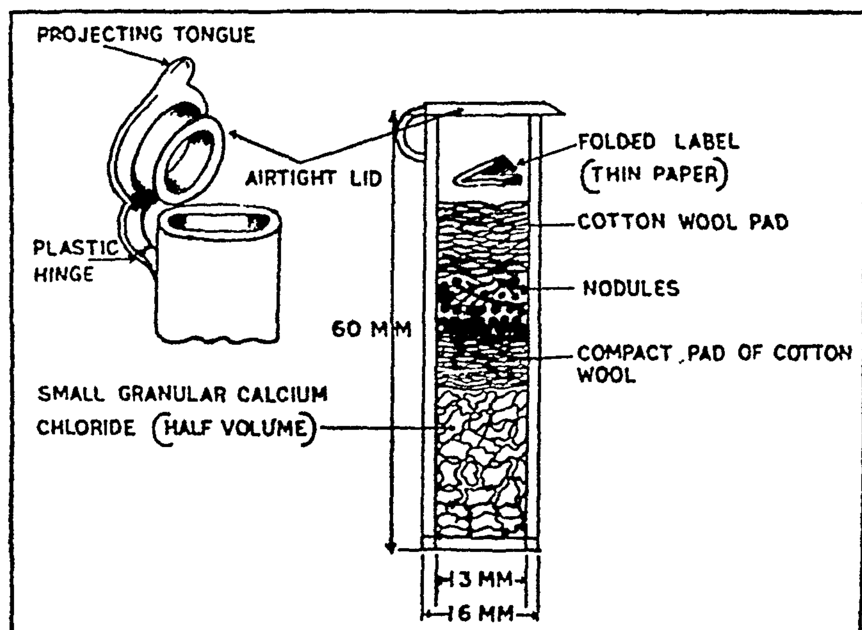


Fig 32

Polythene tubes used for transport of legume nodules by the Division of Plant Industry, C.S.I.R O., Canberra, Australia (After Whyte, R.O., 1958)

Where nodules are necessary to be sent with the plant material, they are packed and preserved according to Dr. F.W. Hely's technique (1956) of Division of Plant Industry, C. S. I.R.O., Canberra, Australia. The nodules are collected freshly by cutting off the portions of the root system with which maximum nodules are found attached. They are cleaned, dried quickly and completely without heating, preserved at a cool temperature in dessicated condition and packed in polythene tubes. Hinged press-shut is sealed on tube mouth with the help of high vacuum grease. They are labelled by a small piece of thin good quality paper numbered in a hard-wearing modern ink.

Every material is well-labelled containing its number, botanical name and other necessary information. The whole package is properly addressed and then transported.

Transport and entry—All plant materials come through sea at prescribed ports of entry, namely, Bombay, Calcutta, Cochin, Kandla, Madras, Negapatnam, Tuticorin, Dhanushkodi and Vishakhapatnam where they are put under detailed examination and if found tained or unsuitable for import according to Plant Protection and Quarantine Laws are either destroyed or returned back. If found suitable, they are treated with chemicals, insecticides, fungicides, etc , and issued *Phytosanitary* (Plant health) *Certificates* as an indication of import permission and free from pests and diseases. These certificates accompany the material wherever it goes.

The import of plants by air is restricted and if has to be done, it can be possible only through a permit issued by the Plant Protection Advisor to the Government of India. Tobacco can not be introduced by air in excess of 18 kilogrammes. Cotton, berseem, flax and sugarcane seeds are prohibited to introduce by letter post.

The commodities given below are generally prohibited for entry into India from respective countries (Renjhen, *et al.*, 1962).

Cocoa and other *Theobromo* spp (Plant and Seed)	—Africa, Ceylon and West Indies.

Sugarcane— — —	—Australia, Fiji Island, New Guinea, Philippine Island and West Indies.
Rubber (Plant and Seed)	—America and West Indies.
Sunflower— — —	—Argentina and Peru.

The import of unginned cotton and Mexican jumping beans from any part of the world is absolutely prohibited.

Cataloguing—As soon as the material is received, it is inspected, treated, identified, numbered and catalogued by the concerned agency.

Multiplication and testing—The introduced material after cataloguing is handed over to the worker or institute interested in testing it Preliminary multiplication and testing are carried out simultaneously at the place where the material is received first. As far as possible the material should be tested under normal conditions for evaluation of desired characters and acclimatization.

For testing, material is grown in isolated area either in nurseries or green houses where they are fumigated. This precaution is taken in order to avoid the dissemination of introduced plant insects and diseases, if any has accompanied by chance, into the production area Here the original introduction, which is usually limited in quantity, is multiplied for further evaluation.

During testing, the material may adapt or may not adapt to the new locality or area. **The ability of crop to become adapted to a new climate is termed as acclimatization.** It is co-adaptive process in which both heredity and environment are in a dynamic state and, therefore, it is determined by the level of adjustment between the two.

Heredity—Acclimatization is determined by the four hereditary factors, *viz.*, mode of pollination, range of variability within the crop, longevity of the crop and its susceptibility to mutations. The cross-pollinated crops are easily and more rapidly acclimatized than the self-pollinated crops because in them there are frequent cross-pollinations giving rise to a large number of gene-recombinations, out of which at least some may be adapted to the new environment A crop with maximum variation is adapted easily

and, therefore, the pure-lines, usually with no variability, are subjected least to acclimatization. The rate of mutation within the material is another factor which influences its acclimatization in the new climate. Higher the mutation, easier and rapid is the adaptation. Mutations are more frequent in cross-fertilized crops than in self-fertilized ones, and therefore, they are easily acclimatized than the later crops.

Environment—A change in environment may show unexpected and unexploited results. The crop varieties adapted only to a particular climate are likely to fail in the new climate. Such varieties may adjust in closely related agrobioclimatical areas. For other crops also more alike the two environments easier is the acclimatization.

Utilisation—During testing, the material found undesirable is discarded and suitable one is utilized further in any of the following ways :

(i) Growing of introduced material *en masse*,
(ii) Selection of desirable plants from it, or
(iii) Using as the parent in hybridization.

If the entire material proves uniform and promising, it can be used directly as a new variety. But the introduced material rarely proves superior to local *en masse* and, therefore, seldom used directly as an improved strain. In case it does not prove uniform, the promising plants are selected during the course of acclimatization and can be utilized either as a new strain or parent in crossing Mostly the introduced plants possess only a few superior and desirable characters like disease resistance, winter hardiness, stiff straw, etc , and, therefore, are invariably used as the parental material in hybridizations to incorporate their superior traits into already adapted local varieties.

Maintenance—The introduced plant materials are maintained in viable condition so that they may be used again by workers on some future date.

USES AND ADVANTAGES

'Plant introduction and acclimatization' is used **when the entirely new crops,** already of no occurrence in the country, **are**

to be grown and given widespread cultivation. Benefits from such new plants to Indian agriculture and industry are well known.

When the particular characters are not available in the local material, the varieties possessing them are imported from outside and their blood is injected into the local varieties to ginger up the production.

The plants are introduced **when** the **variation** in whole available material **is exhausted completely** and no results are obtained by hybridization. Although the variation is also available in nature or can be created artificially in gamma gardens, it takes comparatively more time in procurements than that available in the material already at hand. This is where the work of introduction and acclimatization looms large.

Above all, greatest advantage of plant introduction and acclimatization is this that it is the **most easiest method of crop improvement in plant breeding.**

DISADVANTAGES

Introduction of harmful crop diseases, insect pests and weeds—The uncontrolled import of plants in the past was found responsible for frequent introductions of harmful insects, diseases and weeds, and such cases are quoted below (Renjhen, *et al.*, 1962) :

Diseases : (1) Late blight of potato (*Phytophthora infestans* (Mont de Bary)— A serious disease of potato introduced into India in 1883 from Europe, and is now well spread in all the potato growing parts of India

(2) Flag smut of wheat(*Uracystis tritici* Koern.) —It was introduced from Australia and is now very common in Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh

(3) Leaf disease of coffee (*Hemileia vastatrix* Berk and Br.)—It came into India in 1876 from Ceylon and is now widespread wherever coffee is grown in the country.

(4) Fire blight of apple and pear (*Erwinia amylovora* (Burrill), Winslow, *et al.*)—This disease was introduced from England in 1940 and is popular in Uttar Pradesh.

(5) Bunchy top of banana, which was introduced from Ceylon in 1940, has since spread widely in Kerala, Mysore, Orissa and West Bengal.

Insect pests: (1) Potato tuber moth (*Gnorimoschema opperculella* Zell.)—It entered India in 1900 from Italy and is now widely distributed pest of stored and field potatoes all over the country.

(2) Woolly aphis (*Eriosoma lanigerum* Hausm.)—It is the introduced and serious pest of the apple causing substantial losses to the crop in areas of North India.

(3) Fluted scale (*Icerya purchasi* Mask.)—This pest entered the country through Ceylon from Australia probably on wattles before 1928 and later became a serious peet of citrus.

Weeds: *Argemone mexicana L.*, *Eichornia crassipes* Solms, and *Lantana camara L.* are among some of harmful and undesirable weeds which also entered our country along with the foreign material and are now widespread over entire country causing a great loss to crops.

But serious cases of such introductions and outbreaks of major crop pests, diseases and weeds are few and far between, and occurred in an era when plant protection and quarantine techniques were neither coined nor carefully practised in our country. With our present knowledge of advanced plant protection and quarantine methods there should be no more further undue fear from such incidental accidents which are rare on score.

ACHIEVEMENTS

From time to time, the numerous new plants as well as new strains of the plants already under cultivation in the country had been brought from abroad in the past by colonizers and other agencies These plants have assumed as much economic importance as the native ones and are contributing a huge share in the country's prosperity Some of the important introductions and their acclimatization in India are enumerated here in brief

New plants :

(1) **Crops**—Several agricultural and industrial crops such as maize, potato, sweet-potato, groundnut, chillies, coffee, para-rubber, cinchona, berseem, *Amaranthus edulis*, *Chinopodium quinoa*, French and Lima bean, pumpkin, American cotton, Russian comfry (*Symphytum peregrinum*), launku (*Sechium edule*), mitha karela (*Cyclanthera pedata*), Ipecac (source of emetin), mahogany, tung tree, teasal, annatto (source of edible dye), pimento, tapioca, chinar, willows, etc , are the examples of introductions which exceeded all expectations of their importance at the time of acclimatization and at present also affect the Indian economy considerably.

(2) **Fruits**—The common fruits like guava, grape fruits, custardapple, pineapple, papaya, pumpkin, cashew-nut, cacao, chiku (sapota), litchi, loquat, tomato and several others were imported in the past and are contributing a lot to the wealth of fruit industry in the country.

(3) **Ornamentals**—Many of the ornamentals such as *Peltophorum*, *Cassia*, *Quisqualis*, *Colvillea*, gulmohar, *Bougainvellea*, *Jacaranda mimosaefolia*, *Spathodea campanulata*, phlox, pink, salvia, aster, snapdragon, etc., are foreign introductions which to-day enhance the beauty of gardens all over the country.

New strains of crops :

(1) **Utilized** *en masse*—Plant Introduction Division of I A.R.I. has introduced many varieties of crops and vegetables and tested them under Indian conditions. Several of them have been found useful for direct utilization and have drawn the attention of farmers Some such promising strains are given crop-wise below :

Wheat—'Ridley,' a *Triticum aestivum* wheat variety introduced from Australia, is very popular among hill farmers and covers thousand acres of area in the hill regions of Punjab, Himachal Pradesh and Uttar Pradesh. In Himachal Pradesh alone the area is estimated to be above 20,000 acres.

Sonora 63 and *Sonora* 64 are the Mexican wheat varieties introduced by I. A. R. I. in 1962. They gave 5,000 to 6,000 pounds yield per acre during 1964 and are still under cultivation.

Oat—Kent, a type of milling oat from Australia, has proved very good for cultivation in India for use by the breakfast food industry. Before adapation of this oat, 30,000 maunds of the industry's annual requirement for processable grains had to be imported from Australia. A steady cut in the imports has been made possible by spreading the cultivation of this new variety. Besides this, "Flaming Gold", "Overlant", "Green of Mountain" and "Grey Algerian" are the introduced fodder oat varieties recommended to farmers for general cultivation



Fig. 33

'Kent', a milling variety of oat introduced from Australia is meeting the whole requirement of breakfast industries in India (*After H B. Singh*, 1957).

Cowpea—Three grain varieties, viz , Branco from Brazil and E. C. 4211 and Cream Pea from America, and two fodder varieties, viz., B. C. 4216 and E. C 4893 from America have been found very suitable for cultivation in different seasons in India.

Peas—"Mahndordet", white and bold seeded, and "Rimpus", blue and round seeded, varieties were originally introduced from Germany and are considered very useful for the harvest of dry peas to use in processing.

Rice bean—(*Phaseolus calcaratus*)—Two green-seeded early varieties, one from U. S. S. R. (E. C. 12436) and the other from China (E. C 16167), were introduced and are very famous for their dwarfness among the farmers of eastern hills

Soybean—Many varieties like "Monetta", "Palmetto", "Clemson", "Seminole" and "Willomi" introduced from America and "Herman 36", "Herman 107" and "Glycine-2" from Australia have been found good for cultivation in India to meet the requirement of Antibiotic Industries.

Garden pea—Two American varieties, viz , "Bonnevile" (mid-season) and "Early Badger" (early), both wrinkle seeded, are considered very good for vegetable purposes They are being grown largely in Delhi, U. P. and Poona areas. An another variety "Sylvia" from Sweden also deserves to be popularized for its very good quality of edible pods without parchment.

Tomato—"Sioux," a high yielding, early-ripening variety suitable for cultivation in hill areas, was introduced from the U S A This variety now has become very popular in Andhra and Madhya Pradesh

Onion—"Texas Early Grano" is high yielding salad onion introduced from U S A and now growing well under Indian field conditions

Watermelon—Two watermelon varieties, viz., "New Hampshire Midget" from U. S A and "Asshi Yamato" from Japan have been found suitable for adoption in India

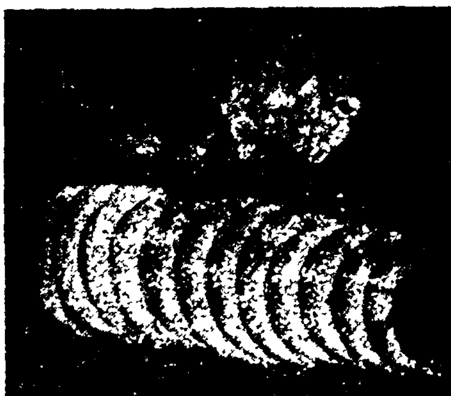


Fig 34
Sylvia, a wholesome edible podded pea introduced from Sweden (*After H B Singh*, 1957)

Fruits—Fruit introductions include "Tropical Beauty" apple from Australia, grape varieties as "Beauty Seedless" from America and "Pearl" from Yugoslavia, varieties of soft fruits or berry fruits and deciduous fruits from Israel Besides this, steps have also been taken to introduce plants of edible nuts such as walnut, hazel, pecan, and filbert from America and Italy.

(2) **Utilized by selection**—The newly introduced varieties, which were not found suitable for direct utilization, had been carried out under selection The fruitful results of such selection

are "Improved Ghana" variety of *bajra*, "Pusa lal" and "Pusa sunehari" varieties of sweet-potato, "Pusa bas-mati" variety of vegetable cowpea; "Japanese white" and "40 Days" varieties of radish; etc



Fig. 35
Improved Ghana, a *bajra* variety selected from the material introduced from Ghana (*After H. B Singh*, 1957)

(3) **Utilized in hybridization**—Many of the varieties introduced from outside have been found to possess useful characters like disease and insect resistance, stiff straw, etc, and, therefore, some of these in wheat, cotton, maize, tomato, peas, carrot and turnip have been used profitably as the parents in crossing with Indian stock Almost all N. P. wheat and hybrid maize varieties released in recent years or about to be released have some of the superior characters incorporated from the introduced varieties. The tomato variety "Pusa Ruby" is a selection from the cross "Sioux" and "Meeruti" and combines the uniform fruit ripening character of Sioux and the all-round hardiness of Meeruti. An another tomato varietv 'Pusa Early Dwarf" is also a selection from the cross between "Red cloud" (American) and "Meeruti". Pusa Red Plum is the cherry tomato also developed by a cross between Indian and South American species.

Almost whole of the credit for these achievements goes to Dr. Harbhajan Singh of I.A.R.I., New Delhi, who has produced many crop and vegetable varieties from the introduced material. Still the work is on progress path and in words of Dr. Swaminathan, wheat yield in India may be raised to 10,000 lbs per acre from the introductions like Sonora 63 and 64 varieties. Hence, it is not now difficult to visualize the importance of 'Plant Introduction and Acclimatization' in agriculture.

Expedition :

In the year 1955, the Botanical Survey of India sent a team to Bomdila, NEFA and later during March-May, 1961, an I. A. R. I. team explored the area between Butwal and Pokhra, and Pokhra and Muktinath in central Nepal. Similar expeditions like six botanists to Russia and specialists of Central Rice Research Institute, Cuttack, to different regions within the country are the notable efforts towards plant introduction These parties collected valuable living plants and herbaceum specimens which are of great significance in crop improvement.

Questions

1. What do you mean by 'Plant Introduction and Acclimatization'? Define them separately and state when this method of improvement is adopted in crops?
2. On the basis of relationship between the introducing and being introduced places, how can you classify the plant introduction into different types and when we say plant introduction do you mean usually to which type?
3. Give a short account of history of plant introduction in India for evaluating its progress
4. Describe the structure of present organization of plant introduction in India and discuss its functions in detail.
5. What steps are involved in the procedure of plant introduction? Mention serially.
6. What type of material and in which form must be imported from outside the country?
7. Why the cross-pollinated crops are more easily adapted in the new locality than the self-pollinated crops?
8. From which type of place the needed material must be imported and why?
9. Through what ways, the plant material can be procured? Describe briefly.
10. Discuss briefly the factors determining the acclimatization of the introduced material in the new region.
11. 'In what different ways' the introduced material is utilized in the country?

12. The imported plant material is rarely useful *en masse*. Explain why?

13. What are the advantages and disadvantages of plant introduction and acclimatization? Illustrate the answer with examples.

14. Describe the following crop varieties giving the crop to which they belong and the way in which they have been evolved :

    Ridley, Sonora 64, Kent, Early bager, Sioux, Tropica beauty, Improved Ghana, and '40 Days'.

15. Comment upon the following :
    Chairman of the Plant Introduction (Co-ordinated) Committee of I. C. A. R., Phytosanitary Certificates, Way of entry of introduced plant material, Dr. H. B. Singh, and Pusa Red Plum.

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CHAPTER 10

MUTATION BREEDING

The genius researches of Muller (1927) and Stadler (1928), almost 43 years ago, gave birth to the 'mutation breeding' which represents a new departure from the conventional breeding procedures in agriculture and is considered a latest addition to them. In fact, it has opened a new era in the plant breeding and is commonly used now-a-days for crop improvement in agriculture.

DEFINITION

Mutation, in general sense, means the sudden heritable changes in an organism other than those due to Mendelian segregation and recombination, whereby the progeny may exhibit an altered shape, size, form or composition This term 'mutation' was coined by De Vries in 1900 for the first time and he derived it from the Latin word *'mutare'* meaning to change Since then it has been widely applied to cover up all kinds of hereditary changes, may be genotypical or phenotypical, resulting from germinal alterations (i) in chromosome numbers (**chromosomal mutation,** i. e., **ploidy**), (ii) in chromosome structure (**chromosomal aberrations**), (iii) within individual genes (**gene mutations**), or (iv) in somatic parts (**somatic** or **cytoplasmic mutations**).



Fig 36

Hugo de Vries (1848-1935), a Dutch Botanist who formulated *"The Mutation theory"* in 1901.

Mutations have become very common in these days and are usually used in restricted sense for invisible changes, physical or chemical, within the individual genes, i. e , gene mutations. Gene mutations are defined as **the changes in the structure of**

individual genes, i. e., intragenic changes and are also designated by many other synonymic terms such as **point mutations, factorial mutations** and **true mutations.** Gene mutations bring changes into genes without adversely affecting their reduplication capacities in hereditary channel and neighbouring genes even if they happen to be identical with them.

Gene mutations are of considerable importance in plant breeding for further progress because they indeed provide the raw material for evolution as well as for recombination and selection. Whatever has been achieved by hybridization and selection in the past was due to creation of such variations in nature spontaneously.

The researches of Muller, Stadler and further studies on gene mutations have made it quite possible to induce gene mutations artificially with the help of mutagenic agents. Now, with this advent the genotypes and phenotypes of plants are under human control and can be changed at any time according to desired niches and needs. This **creation of mutations at will and their utilization for the production of new crop varieties is known as mutation breeding.** In recent years, it has become a common trend among all the plant breeders, not only in India but all over the world, to use either mutation breeding or polyploidy breeding as a magic tool for creating new varieties because by their application entirely new and original characters are produced in a variety as against hybridization and other methods where merely the already present characters are combined together into form of a new variety.



Fig. 37

H. J Muller (1890-1967), the pioneer American radiation geneticist who reported the artificial induction of mutations in animals by X-rays in 1927

SPONTANEOUS VS. INDUCED MUTATION

Mutations, according to their origin, are of two types, *viz.*, spontaneous and induced. The spontaneous mutations

arise automatically in nature due to subjection of the living organisms to treatments of naturally occurring agents such as electric currents, atomic rays and particles, injuries, disease and insect attacks, temperatures, chemicals, etc., which are suspected to be mutagenic in effects. The mutations observed by early workers were of such origins. These mutations remain arising constantly and continuously in nature and are the basis of crop improvement by conventional breeding methods.



Fig 38

L J Stadler, a pioneer American plant breeder who induced the mutations in plants in 1928 and exploited the possibilities of crop improvement by mutation breeding for the first time.

Spontaneous mutations are very slow and infrequent in nature, perhaps once in every million individuals. They are in alignment of nature, out of which only an exasperatingly small proportion is useful to plant breeder and, therefore, they are not sufficient to speed up the improvement of cultivated plants in accordance with increasing human needs. This slow occurrence and uneffectiveness of spontaneous mutations forced the men to induce the mutations at will by artificial means which are known as induced or artificial mutations The precise differences between the two types of mutations are given in Table 10.

The artificially induced mutations are similar to those produced spontaneously in nature due to the fact that the kinds of changes produced are alike to those created by spontaneous mutations. The spontaneous and induced mutations are, therefore, not fundamentally different from each other.

Table 10. Comparison between spontaneous and induced mutations

S. No.	*Difference in*	*Spontaneous mutations*	*Induced mutations*
1.	**Origin**	They originate spontaneously in nature.	They are induced artificially.
2.	**Occurrence**	They are under the control of nature and, therefore, remain continuously arising in nature automatically.	They are man-made and, therefore, occur when man induces them, otherwise never found.
3.	**Source**	They are produced by naturally occurring mutagenic agents such as electric currents, atomic particles and rays, temperature, variations, etc.	They are produced by subjecting the plants or any other organisms artificially to mutagens such as Gamma rays, X-rays, neutrons, ultraviolet rays, etc.
4.	**Frequency**	Their frequency of occurrence is very slow and infrequent	Their frequency of occurrence is higher than spontaneous mutations because they are induced by human being intentionally for increased occurrence.
5.	**Use**	They are the basis of crop improvement by conventional methods.	They are the basis of mutation breeding specially when the further improvement in crops is not possible by spontaneous mutations.

ARTIFICIAL INDUCTION OF MUTATIONS

Artificially, the mutations are induced by the substances known as mutagenic agents or mutagens. At present various kinds of mutagens and mutagenic facilities are availabe for mutation breeding and they have been evolved by persistent efforts of scientists. The different mutagens employed for artificial induction of mutations are :

(A) Radiations : *Ionizing*

(i) Alpha rays (α),
(ii) Beta rays (β),
(iii) X-rays,
(iv) Gamma rays (γ) and
(v) Neutrons.

Non-ionizing

(vi) Ultraviolet rays (UV),

(B) Chemicals.

Before going into their details, the terminology concerned with them is given in brief below for the easier grasping and understanding of mutagens and their action.

The elements are composed of tiny, ultra-microscopic units known as atoms. An atom consists of a dense **nucleus** around which, i.e., in orbit, revolve small negatively charged bodies known as **electrons** The nucleus contains two types of particles, **i. e., protons and neutrons**. Protons are positively charged and very large in comparison to electrons about 1800 times more in weight, but they are equal in number thereby creating a condition of neutrality. For instance, hydrogen has one of each, oxygen has eight of each, carbon has six of each, and uranium has ninety two of each. Neutrons are without charge and have a weight about equal to that of protons, thus they add weight to the atom without altering its charge. Besides this, they also play a part in the stability of the atom.

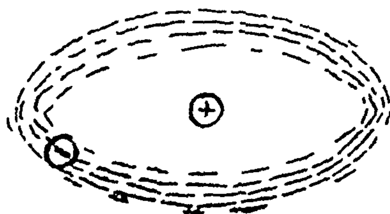


Fig 39

A hydrogen atom consists of one proton and one revolving electron.

The atom contains a high amount of bound energy and when its neutron number is altered there may arise such an unstable condition in which the atom tends to split or to give off particles or energy thereby achieving stability. Such unstable atoms are known as **radioactive isotopes or radioisotopes** and defined as the atoms of same element having different weights For illustration the carbon atoms can be taken which has normally six protons and six neutrons in its nucleus and six electrons in orbit around the nucleus This atom is called carbon twelve, C^{12}, but there is another form of carbon atom which has eight rather than six neutrons. This atom has a weight of fourteen rather than twelve and, therefore, it is called C^{14}. These extra two neutrons create a state of instability and the heavy carbon atom tends to give off radiation.

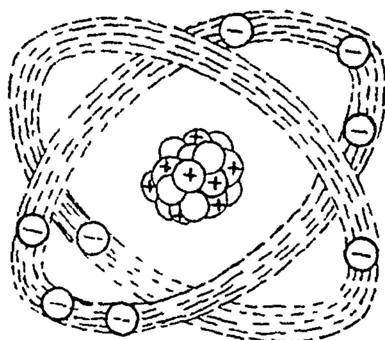


Fig. 40

An oxygen atom consists of eight protons and eight neutrons in the nucleus and eight revolving electrons

The movement of energy, which is given off by radioactive isotopes in either particles or wave form, through a space is considered as **radiation**. The radiation in form of high energy atomic particles, which can transfer their kinetic energy to any matter through which they pass, is known as **particulate** or **corpuscular radiation**. The radiation in form of high energy short-waves, which cause electric and magnetic disturbances affecting the internal structure of matter, is known as **electromagnetic radiation**. The treatment of substances or plants with radiation is called **irradiation**.

During irradiation the high energy radiations, both particulate and electromagnetic, pass through the matter and cause **ionization**. An ion is an atom with either a positive or a negative charge and the ionization is the process in which ions are produced. The particulate radiation can produce ionization when a fast moving charged particle passes through a matter and pulls an electron out of the orbit of an atom. This atom, then becomes an ion with a positive charge because the one

extra proton in the nucleus will not be balanced by an electron in the orbit. The ejected electron gets attached to the another atom of the substance, thus forming pairs of positive and negative ions The neutrons, being without any charge, do not cause expulsion of orbital electrons in this manner, but they can cause ionization by striking the nucleus of an atom in the substance which results in the excitation and emission of the charged particles. The emission, in turn, produces ionization by affecting orbital electrons. Electromagnetic radiation also causes ionization but in a secondary manner. The energy absorbed from waves creates the state of instability and thus the absorbed excess energy is dissipated by throwing off one of the orbital electrons. This electron produces additional ionization since it is a charged particle moving through the matter. Such radiation mutagens which cause ionization are also known as ionizing radiations.

The units of measurement of ionizing radiations are many as *r* (Roentgen), *rep* (Roentgen equivalent physical), *rad* (radiation absorbed dose) and *rem* (Roentgen equivalent man) Their details are given in Table 11.

Alpha rays · Alpha rays are radioactive rays made up of two protons and two neutrons with positive charge. They are emitted chiefly by the isotopes of heavier element and when pass through a matter create strong ionization *They have very little penetrating power in living tissue because being positively charged they are slowed down readily by the negative charges in matter and cause usually the chromosomal aberrations.*

Table 11 Units of measurement of ionizing radiations

Units	*Measured in*	*Radiations measured*	*Use in general*
Roentgen	Air	X-rays and Gamma rays	Monitoring
Rep	Soft tissue	Particulate	Biological research
Rad	Any material	All types	Biological and physical research
Rem	—	All types	Records of human exposures.

Beta rays : Beta rays are also radioactive rays with negative charge. They are high speed electrons emitted from the nucleus of an unstable atom. They have very less ionizing power but greater penetrating power than alpha rays. They vary in their penetrating power because they express considerable variation in the energy with which they are emitted. *Being negatively charged, they are slowed down by positive charges and lose energy readily. Thus they are not very penetrating. They cause both chromosomal aberrations and gene mutations.* P^{32} and S^{35} are used as the source of these rays, and are available in form of chemicals out of which solution is prepared and desired treatment is given.

X-rays: X-rays are electromagnetic radiations having wave length much shorter than those from visible light. They are produced in a broad range of energies. Soft X-rays of longer wave length (10 to 1 Å) are less penetrating but more densely ionizing than the shorter wave length (0.1 to 0.05 Å) hard X-rays. Average wave length of X-ray from X-rays machine is generally 0 5 Å. They have relatively sparse ion density, i. e., effects are due to sparsely ionizing electrons X-rays transfer their energy to the atom of tissue through which they pass, which causes an ejection of planetary electrons due to ionization and excitation of atoms or molecules and consequently giving rise to chromosomal and gene mutations The source of X-rays treatment is X-ray machines installed in rooms.

Gamma rays : Gamma rays are electromagnetic radiations similar to X-rays in their physical characteristics and actions on the organisms. They are, therefore, natural X-rays *but of very short wave length by virtue of which they are more penetrating.* Gamma rays are of same nature as is light but have shorter wave length and, therefore, *contain high energy.* Most of the Gamma rays have wave length of less than 0.01 Å as compared to 4000 to 7000 Å of light and 0.5 Å of X-rays.

Gamma rays ionizing effects are also due to high electrons they eject from the atoms of tissue through which they pass. These radiations are detected and counted usually by means of electronic instruments such as Geiger Muller counters or Scintillation counters The material is treated with Gamma rays usually in Gamma garden and they mostly produce gene mutations

Table 12. Summary of different mutagens for comparison

S. No.	Difference in	Gamma rays	X-rays	Beta rays	Neutrons	Ultra-violet rays
1.	**Type of radiation**	Ionizing and Electromagnetic	Ionizing and Electromagnetic	Ionizing and Corpuscular.	Ionizing and Corpuscular.	Non-ionizing.
2.	**Wave length**	0 01 Å	0 5 Å	Solutions of different concentrations as needed	—	1000 to 4000 Å
3.	**Energy and penetrating power**	High energy and, therefore, of very high penetrating power.	Less than Gamma rays.	Very less.	High penetrating power.	Very less penetrating power.
4.	**Source**	Gamma gardens.	X-ray machines inside rooms.	Solutions in form of Phosphoric and Sulphuric acid	Generators which are meant for generating neutrons.	UV bulbs or tubes.
5.	**Use in genetics**	For point mutations. Commonly used in genetics.	For both chromosomal and point mutations.	For chromosomal aberrations	For point mutations. Commonly used in genetics	For pollen treatment usually.
6.	**Plant material treated**	Both seeds and seedlings.	Both seeds and seedlings but more commonly seeds.	Both seeds and seedlings but commonly seeds.	Both seeds and seedlings but more commonly seeds.	Usually pollens.

Neutrons : They are electrically netural particles and their biological effects are due to the densely ionizing protons which may be fast as well as slow. *The neutrons may be highly penetrating because due to lacking any electric charge they are not slowed by charged particles of matter and thus tend to move* in a straight line until they have a collision. The sources of treatments are nuclear reactors and generators available with Atomic Energy Department of Government in different parts of the country.

Ultraviolet rays . Ultraviolet rays are non-ionizing with wave length between 1000 to 4000 Å, i. e., of *very long wave lengths and, therefore, do not penetrate the tissue appreciably but simply cause the excitation of planetary electrons which results in increased chemical reactivity inside the tissue.* Thus, their biological effects are only due to excitation and photochemical reactions Because of very less penetrating power ultraviolet rays are not efficient in producing chromosomal and gene mutations as compared to ionizing radiations and, therefore, their use is confined to pollen grains' studies. So far is known, no mutants of economic importance have been produced in higher plants with ultraviolet radiations. Ultraviolet rays are produced in mercury vapour lamps and tubes specially designed for UV rays and treatment is carried out by exposing the desired plant material to them UV rays treatment is relatively inexpensive.

Different irradiating mutagens are listed in Table 12 for easy consultation and comparison.

Chemicals The most powerful mutagenic chemicals discovered so far are the mustard gas and its related compounds such as ethylene oxide, 8-ethoxycaffeine, etc. They are applied to desired plant material in form of solutions and induce both chromosomal and gene mutations

Table 13 Chemical mutagens (After Williams, 1964)

1. *Mustard compounds and lachrymatory substances :*

Substance	Activity	Reference
Mustard gas Sulphur mustard Nitrogen mustard (two forms)	highly mutagenic	(Auerbach, 1949)
Mustard oil Chloroacetone Dichloroacetone	weakly mutagenic	

2. *Alkylating agents* (in increasing order of efficiency in producing sex-linked lethals at a given dose) ·

Ethylene oxide *n*–Butylmethanesulphonate *cis*–1 : 4-Dimethanesulphonoxybut-2-ene *p*-N-*di*-(Choloroethyl)-phenyl propionic acid 1 : 4-Dimethanesulphonoxybutane *p*-N-di-(Chloroethyl)-phenylamino butyric acid *trans*-1 : 4-Dimethanesulphonoxy but-2-ene *p*-N-di-(Choloroethyl)-phenyl valeric acid *p*-N-di-(Chloroethyl)-phenyl acetic acid 1 : 2, 3 : 4-Diepoxybutane D : *p*-N-di-(Chloroethyl)-phenylalanine *L* : *p*-N-di-(Chloroethyl)-phenylalanine 1 : 4-Dimethanesulphonoxybut-2-ene *p*-N-di-(Chloroethyl)-phenyl butyric acid 2 : 4 : 6-tri-(Ethyleneimino)—1 : 3 : 5— Triazine.	(Fahmy and Fahmy, 1956)

3. *Purines and purine derivatives* (in decreasing order of mutagenic activity in bacteria)

Caffeine Theophyline Paraxanthine Theobromine Tetramethyluric acid 8-Methoxycaffeine Adenine	(Novick, 1955)
Nebularine	(Ehrenburg, *et al.*, 1956)

4. *Others*·

Potassium thiocyante	(Stubbe, 1940)
Ethyl carbamate	(Oehlkers, 1943 and 1953)
Formalin	(Rapoport, 1946 and Kaplan, 1948)
Phenols—several	(Levan and Tijo, 1948)
Maliec hydrazide (used widely in agriculture to inhibit sprouting of potatoes)	(McLeish, 1953 and Kihlman, 1956)

Manganous chloride	(Demerec and Hanson, 1951)
Colchicine (inculding mutational changes that are not due to changes of ploidy)	(Franzke and Ross, 1952)

The creation of mutations by subjecting the plants and seeds to ionizing radiations and their utilization for production of new varieties is known as **irradiation breeding.** Among all the ionizing radiations, the X-rays and Gamma rays are most commonly used ones for induction of mutations in agricultural crops because they usually produce gene mutations whereas other radiations induce mostly the chromosomal mutations which disturb the whole set-up of characters in organism. The installation of X-ray machines is possible only in well-protected rooms and the plant material to be treated has to be taken to such rooms for X-irradiation. Thus, the X-rays treatment is cumbersome and imposes a limitation on the number and types of plants to be handled. On the other hand, the gamma rays irradiation is carried out in open garden, specially designed for gamma irradiation, which imposes no such difficulty and, therefore, its use is comparatively more common than X-rays for induction of mutations.

GAMMA GARDEN

Origin : The first Gamma garden of the world was installed in the centre of an isolated area in Long Island near New York about 13 years ago by the scientists of Brookhaven National Laboratory, U.S A Subsequently such gardens were set up in several countries. In India the first Gamma Garden was opened at the Bose Research Institute, Calcutta in 1959 and the second at I. A. R I., New Delhi on 25th August, 1960. The Garden of I. A. R. I. is the largest of its kind in Asia and was designed and constructed by the scientists of I. C. A. R. and Department of Atomic Energy, India. It has been incorporated with several unique features based on the experience got from the working of similar fields in U.S A and Sweden.

Design of I. A. R. I Gamma Garden : "Gamma Garden of I A. R. I., New Delhi, has an area of three acres, the whole of which has been encircled by a wall 3′ thick and 12′ high, built with bricks on either side and earth compacting in the middle.

This wall serves two purposes; firstly, it offers a protective shielding so that no harm is done to the health of individuals working at the outskrits of the garden and, secondly, it helps to regulate entry and work in the garden. Outside the brick wall, a barbed-wire fencing has also been erected to ensure that no unauthorized person enters the garden The radioactive cobalt source is in the form of small pellets weighing about six grams in all. These pellets are inside an aluminium capsule and the capsule is welded to the lead container in which the radioactive cobalt is kept. The strength of source is 200 curies and the cobalt source together with container was purchased from the Atomic Energy of Canada Limited. The radioactive cobalt source can be raised from the lead container by lifting the lid of container The lid travels through guide rods inside a thin aluminium tube and is lifted electro-magnetically by pushing a button in the central panel installed in a room 205′ from the ground, and as soon as it is taken out of the lead container, the whole garden receives gamma radiations. Plants are grown in concentric circles and the whole garden has been divided into eight sectors, each sector allotted to

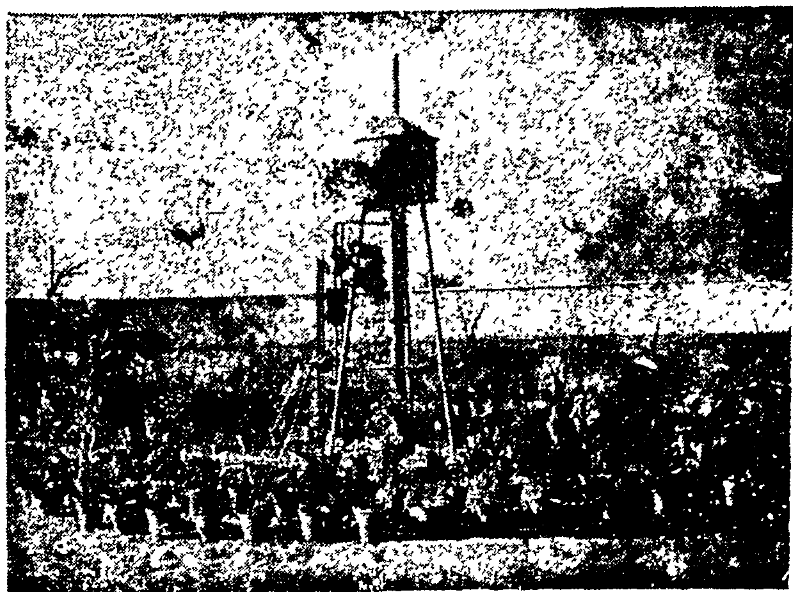


Fig 41
Cobalt-60 Gamma Garden at the I A R I., New Delhi where irradiation is done for crop improvement *(By Courtesy of Bot Div, I A R. I, New Delhi)*

a specific group of plants such as cereals, pulses, fibre crops, vegetables, fruit trees, etc. Irrigation water is pumped through hydrants fixed at suitable intervals. Two radiation monitors, one fixed to the circular wall and the other which is portable and can be moved radially, help to measure accurately the radiation doses received by the plants at different distances from the source. The plants very near the source receive the highest dosage, and those further away, much less. (Joshi and Swaminathan, 1963)."

This Gamma Garden is under the control of the Head of Botany Division, I. A. R. I., New Delhi and is available for experimental uses to all the workers in the State and Universities of India. Any one interested in mutation studies may get needed material, gamma irradiated from here easily.

Radioisotope Laboratory at I A. R I

The plan for setting up a Radioisotope Laboratory at I. A. R I., New Delhi has already been approved for harnessing the nuclear energy for agricultural research. The work of proposed laboratory had begun in first week of July, 1968.

This laboratory will be the first of its type in the developing countries and provide facilities for research of more advanced nature in plant breeding, i.e., how to produce new crop varieties by artificial transmutation of genes. It will also be very useful in studying the fertilizer, utility, insect control through sterlization avoiding large scale use of pesticides, food preservation, moisture conservation and plant disease control.

Apart from Indian students, young agriculture scientists from nieghbouring countries will also be absorbed in the laboratory which will be among the most modern in the world (Statesman, June 17, 1968).

PROCEDURE OF MUTATION BREEDING

Plant material for irradiation: The plant can be treated in any form, i e., seeds, seedlings or cuttings with radiations of different kinds. Some general inferences, which have been drawn from the experimental results obtained by different workers, are given here.



Fig 42

Dr. M. S. Swaminathan, a leading Indian cytogeneticist and pioneer radiation breeder under whose guidance mutation work is being done at I A R. I, New Delhi

Seeds · Aged and soaked seeds show greater frequency of induced mutations than the fresh air dried seeds Seeds with extremely low water content also show higher radiosensitivity as indicated by injuries in R_1 and it is, therefore, necessary to see that the water content at the time of irradiation is normal and also they are not too young as well as too old

Seedlings · The plant at any stage of life cycle can be subjected to radiation treatment but usually the seedlings, neither too young nor too old, are irradiated due to their convenience in handling in pots and transportation from nursery easily. The mature plants are less sensitive and neither they can be taken to the source nor the source can be brought to them except some chemical solutions and, therefore, their subjection to irradiation is rather difficult in comparison to seedlings grown in pots Meiotic cells have been found to be more radiosensitive to radiation than mitotic cells and, therefore, plants are irradiated in the flowering stage in order to affect the developing gametes.

Cuttings : In case of fruit trees, where vegetative propagation is followed, the desirable cuttings can be exposed to radiation treatment.

The genetical constitution and radiosensitivity, which vary from crop to crop, also determine the type of material to be treated. Some plants are more resistant to irradiation while the others with the same dosage are more susceptible. Many workers have proved that the plants with larger chromosomes are more susceptible than those with smaller chromosomes Polyploids are generally more resistant to irradiation than their related diploids, and hybrids (F_1) are more resistant than their parents It is also reported that the mutation rate is more in heterozygous material than the pure-lines. This is due to the fact that incomplete

genetic balance increases the tendency to mutate through external influences. Thus, from the practical point of view, the hybrid material of earlier generations is recommended for induction of mutations so that the highest number of mutations can be obtained.

Until and unless full information about genetical constitution of plant material and its radiosensitivity is known, the mutation breeding can not be used as a precise tool for crop improvement in plant breeding.

The amount of plant material, whether it is seed, seedling or cutting, to be treated with radiations depends upon the funds and facilities available and the breeding objective to be sought ; but to obtain sufficient variation for desired achievement, the population must be large enough since the frequency of occurrence of desirable new mutants is so small that they are not likely to be noticed in small number of plant population.

Treatment : For X-irradiation the material is taken inside the X-ray room where it is exposed to X-rays. The seeds are kept in petridishes while seedligs with pots are put before X-ray machines. Due to the limitation of space the large number of seedlings, can not be treated with X-rays. For Gamma irradiation the pot-grown plants are taken into the space reserved for them very near the source in a circle. They are irradiated with required dosage and taken away. For seed treatment a tray is fixed to the aluminium tube through which the radioactive cobalt source travels when lifted from the container and in this tray they are kept and subjected to desired dosage of Gamma rays. Neutron treatment is done by exposing the seeds as well as seedlings to the neutron flush from the generator Beta rays treatment is done with the radioisotopes P^{32} and S^{35} available in the form of phosphoric and sulphuric acids, respectively. The seeds and seedlings to be treated are immersed in solutions of desired strength for specific durations In some cases the solution of radioisotopes is also applied to the soil.

Dosage : The first problem in mutation breeding is to determine the proper dosage of irradiation so that the frequency of desired beneficial mutants can be increased and that of undesirable can be decreased. The proper dose will be one which

gives an appreciable frequency of beneficial mutants on selection and makes the heritability value of yield and other desirable characters highest. This dose varies from crop to crop depending upon the nature and genetical constitution of the plant material. It is a fact that more resistant the crop higher will be dosage required to create the desired useful mutations and vice versa.

The amount of radiation required to kill 50 per cent of the exposed individuals is termed as lethal dose and expressed as L. D 50. The figure of L D. 50 varies with different crops and animals.

The desired dosages are given by manipulating the duration of treatment and the distance of material from the source The radiations are detected and counted most commonly with sensitive electronic dosimeters like Geiger scalers and Scintillation counters.

First irradiated generation: After irradiation, the storage of treated material increases the injuries in R_1 and, therefore, it is removed immediately and sown into the field surrounded by the control material of mother strain Thus the R_1 † generation is obtained. The purpose of planting the control strain all around the treated material is, firstly, to isolate the treated population completely from other varieties so that no intercrossing may occur and hamper the observations on mutagenic effects, and secondly, to compare the treated generation with control, so that effects of irradiation may be observed easily.

Effects of treatment in R_1: The mutagenesis disturbs the normal biological organisation of an organism and this is seen in a variety of ways. The low dosages do not show any severe effects and the plants do not reveal any disturbances. However, the high dosages produce gross visible disturbances These effects are seen in four categories, *viz*, (1) Death, (2) Growth inhibition, (3) Morphological & developmental abnormalities, and (4) Genetic changes. In the first category there is nothing for further study due to the death of plants. The growth inhibition and morphological abnormalities seen in an irradiated plant material

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†The symbol R^1 is used to denote the first generation of material treated with mutagens irrespective of the type of mutagens used, i.e , X-rays, Gamma rays, neutrons, etc Sometimes, instead of R^1, M^1 is also used to denote the same generation. Besides these two, it has become customary to use X to denote the first generation of only X-ray treatment, not any other

may or may not carry any changes of potential interest. The abnormalities seen immediately after treatment are more likely to be of temporary disturbance from which the plants will recover. The true genetic changes, i.e , mutations, though rare, are more useful in the crop improvement than first three types of changes and, therefore, we are more interested in the mutations rather than in other abnormal plants of rare usefulness.

Mutation effects may be due to all the three types of mutations, i e., chromosomal, cytoplasmic and gene changes.

In whole of the irradiated plant population only the few plants reveal the mutation effects ; because the naturally occurring material when subjected to artificial changes, responds very less on account of its well established stabilization in constitution in course of natural evolution. Mutation effects may differ even within the same plant from tiller to main stem as has been reported in rice. Within the individual plant all as well as few characters or even only one may be affected by mutation depending upon the nature of change due to mutation In chromosomal mutations, (polyploidy) normally all the plant features are affected while in other types of mutations only few or even single characters are affected. Among all the characters which one is most susceptible to mutations is again uncertain since all plant parts and processes are under genetic control and mutation may affect any known character.

Gene mutants may differ from the parental strain in any character, i e., internal or external, morphological, physiological, or biochemical, etc., which immediately may or may not express phenotypically. Mutations may be either recessive or dominant, but the first are more common which can not express phenotypically until and unless two recessive genes come together and become homozygous. This expression requires the intervention of one or more generations after their occurrence for recombination of two similar recessive genes to affect their phenotypical appearance in the population.

Selection in R_1 : Almost every suspected plant's or tiller's ear is picked in R_1 and kept separate for further investigations.

R_2 Generation : In R_2 the seeds of individual ears from the R_1 are grown in progeny rows because the R_1 ears are affected

independently by mutations as stated earlier under effects. Instead of ear selection, sometimes one or three grains from R_1 plants are picked up and sown in R_2 rows and they are known as one-plant-one-grain or one-plant-three-grains methods respectively They are considered more efficient than ear-to-progeny-rows method because, firstly, the land and labour expenses are reduced considerably and secondly, it is easier to distinguish the desirable mutants from the original variety in R_2. It is good to sow 14 to 15 seeds in each progeny row to avoid and eliminate every error which may creep in due to too many or too less seeds per row. After every tenth progeny row, a row of original variety is sown as a check for comparison

Whatever may be the method, whether ear-to-row or grains-to-row, the sowing of progenies of individual plants in separate rows facilitates the detection of mutants in R_2 and their breeding behaviour, i e , variation so obtained is whether inherited or by chance. When two or more mutants of R_1 segregate in R_2 generation, the probability of their detection will be increased and this detection will be more reliable than R_1 Even if the R_2 population is small and only one mutant segregates in this population, it will be observed immediately in comparison to neighbouring normal plant and thus it will be easily detected.

Screening and selection in R_2. Screening of the irradiated material is also started in R_2 rather than in R_1 generation even for the dominant mutants, because, (1) in case of recessive mutants, which are more frequent than dominants, both locii are rarely mutated and, therefore, segregation must be permitted for letting them to come in homozygous condition so that they can be isolated and (2) in case of dominant the frequency is so small that it may be rather difficult to detect the same in R_2 generation. Secondly, it is also possible that appearance of dominant characters may be due to natural intercrossing, intermixing or loss of genetic material during sexual reproduction rather than induction of mutations Both these difficulties of recessiveness and infrequency of dominant mutants are automatically lessened in R_2 and screening becomes very easy in irradiated material.

It has also been commonly observed that a large population is taken in R_2 to avoid the difficulty of low frequency of

dominant mutants and mutation breeding is practised where efficient screening techniques have been developed in a material or where screening is very easy as in disease resistance. But now due to our sound background and advanced theoretical knowledge of mutations, it has become quite possible to control the mutations in any desired direction and thus the chances of inducing beneficial mutations are enhanced considerably. However, in Sweden, Japan and other countries by the application of biometrical techniques to mutation breeding some better screening and selection methods have been developed for easy isolation and detection of desired mutants.

Drastic mutants are often obtained in high dosage of mutagen treatment. They occur merely due to morphological changes, such as shortening, thickening or thinning of already existing organs and never by any radical organic alterations. In wheat drastic mutants like branched stem, leaves without legules and auricles, etc., have been reported. These drastic mutants are very apparent and attract the attention of plant breeder, but from practical point of view suck mutants are of no use and, therefore, he must be quite aware of disturbances and misleadings caused by such mutants.

More efficient the technique of screening, better are the chances of obtaining mutations of varied and desired kinds

In R_1 the seeds from different ears of desired plants are collected separately. Sometimes the seeds of like mutants, which are called aberrant types, can also be mixed together.

R_2 to R_5 generations: In R_3, plant to progeny rows are raised with original variety as check. Fourteen to fifteen plants are grown per row, but the larger the number of plants the better it is. If all the plants in R_3 lines are true to type as in R_2 they are called mutants Here the slightly differing homozygous and high yielding lines are selected from them. The true breeding lines are carried in F_4 and compared in progeny rows with original strain as control. In R_4 all the inferior lines are eliminated completely. If, after first inspection, the homozygous mutants appear productive in R_4, they are included in small R_5 trials where the best ones are selected for the full yield comparisons in K_6 and others are kept in mutation collection.

Yield trials : The yield trials are begun at a moderate rate in R_5 generation and only the highly useful mutants are comprised. If in this trial the differences between mutants and parental strain are very slight regarding yield, they may be further tried in R_6 and R_7 and then released as superior strains provided it is superior in desired character for which mutation breeding was started initially. If the mutant gives very less yield in comparison with check but is superior in the desired character, it may be carried in hybridization This brings all the desirable characters together into the mutant. All the techniques of crossing and other steps are the same as those of conventional hybridization programme.

The regional yield trials may also be carried on simultaneously with main yield trials

Time taken: The time taken by mutation breeding procedure for desired improvement varies from problem to problem depending upon the nature of improvement needed and the stage at which it is obtained. If combined with hybridization it takes same time as is taken by conventional breeding procedures, otherwise less If the desired improvement is obtained in R_2, as awned character has been obtained in N. P. 799, it takes very less time The success so far obtained shows that generally mutation breeding takes very less time for production of superior strains as compared to other breeding procedures.

Precautions : The first and foremost precaution in mutation breeding is to get sure that the mutants isolated are really due to mutations and not due to intermixing, crossing or segregation. For this, every other possibility of mode of origin of variations in individuals must be excluded from the mutant population.

The second precaution is that the plant breeder must be well trained in all breeding techniques including mutations and very keen observer so that he can pick up the slightest deviation in the treated population and include in his selection for further investigations.

APPLICATION OF MUTATION BREEDING

Mutation breeding, like the conventional breeding methods, can be used in all the three types of crop plants, *viz.*, self-pollinated, cross-pollinated and vegetatively propagated

1. **Mutation breeding in self-pollinated crops :** The self-pollinated crops are genetically homozygous in which selection has no meaning until and unless some variation is either present already or created artificially. Besides this, the mutants in self-pollinated crops can be detected easily on account of purity and true breeding nature of their progeny Due to these two facts, it is this class of plants with which the mutation breeding has been used most widely and commonly.

2. **Mutation breeding in cross-pollinated crops :** The cross-pollinated crops are usually heterozygous and, therefore. their normal variability and intercrossing within the variety give rise to different types of progeny which hamper the detection of mutants in the population. Secondly, most of the workers are of opinion that the naturally occurring genetic variability in these crops is in abundance and it is totally unnecessary to use mutation breeding as a source of increasing the variation in the cross-pollinated crops.

3. **Mutation breeding in vegetatively propagated crops :** The vegetatively reproduced plants are highly heterozygous and they hardly permit the purposeful improvement by conventional breeding procedures because the sexual reproduction involved in them destroys all valuable characteristics of the vegetatively propagated variety. In such crops it is always advantageous to use mutation breeding for adding new desirable characters in them.

Particular application : Over and above, the application of mutation breeding is unavoidable under the following problems of crop improvement :-

1. When whole of the naturally occurring variability is exhausted . On account of intensive and continuous improvement work in crops, a stage is reached where whole of the existing natural variability is exhausted and, therefore, no further improvement can be achieved by any of the traditional breeding methods If some variability remains unexploited or arises spontaneously, it is insufficient for the further needs of improvement. Under this situation, the only way is to induce variability artificially by mutagens and resort to mutation breeding for further improvement. In other words, it can be stated that when a particular character of economic importance is not found to exist in the

already occurring plant material, the only way to create it is mutation.

2. *When a gene for desirable improvement is known to exist but unattainable :* Sometimes a desirable gene is found to exist in nature but due to geographical, political or biological barriers it may not be possible to incorporate it into the needed variety by old fashioned breeding methods. If the plant material containing the desirable gene is found in another country from where it may not be possible to procure it due to unlike climatic conditions and introduction limits. Even if it is found within the country, the incompatibility due to its presence in distantly related species or genus may not allow the transference to the needed commercial varieties. In addition, it may carry associated unfavourable characters due to close linkage which further makes the transference undesirable. Under such circumstances, the improvement by conventional methods is impracticable and the application of irradiation breeding is inevitable.

3. *When a desirable gene is known to exist and attainable but not desirable to attain it :* Mutation breeding is specially useful in improvement of the single inherited character in a delicately balanced variety. When dealing with highly developed variety, the plant breeder is reluctant to use backcross method, which is equally applicable, because it may disturb the balanced combination of genes and thus, the variety may loose some good characters. This situation arises when an outstanding variety succumbs to a race of disease or lacks in one or two morphological or physiological characters. This situation can be easily illustrated by taking the example of wheat variety N. P. 799, which is an otherwise good and well-developed variety but is lacking in awns. Indian farmers prefer awned varieties in the belief that the presence of awns prevents the damage to grains in ear by birds. The "awn" character is found in other N. P. wheat varieties from where it can be easily transferred into this variety by backcrossing, but it spoils the other desirable characters since the variety is highly bred. This problem was realised from farmers' need and the irradiation breeding was applied. Ultimately, N. P. 836 wheat variety, which is fully awned and already under cultivation, was produced by Swaminathan and his associates. This achievement clearly suggests that at least in

crops like barley, wheat, etc., mutation breeding is highly desirable for transference of a specific attribute to an otherwise highly bred strain.

4. The application of mutations in special problems such as breaking up close linkage and transferring the little segment of a chromosome to non-homologous chromosome has been found very useful and advantageous.

Controversy over application: At present there is great controversy over application of mutation breeding in crop improvement and two schools of opinion are in existence. One school of thought is of opinion that mutation breeding is of no avail to apply in agriculture because:

1. Natural occurring variability in crops is already sufficient to meet the demand and has not been completely exploited by conventional methods.

2. Most of the induced mutations are recessive and harmful with very low frequency of beneficial mutations.

With such a relative wealth of natural genetic variability in contrast to recessiveness and infrequency of induced beneficial mutations, plant breeder can not afford to devote the part of his resources for application of mutation breeding.

On other side, the second school of thought, consisting of Gustafsson and his associates, is entirely of different opinion:

1. Gustafsson says that the existence of genetic diversity does not mean that it is most appropriate or even sufficient for crop improvement according to human niches and needs.

2. Gustafsson is of opinion that with our advanced knowledge in mutations, it is quite easy to control the frequency of mutations in desired directions. He states that by mutation 100% harmful genes are not produced but at least few beneficial genes are also created and there is great difference between 100% and 99.99% harmful genes. In this connection he has estimated



Fig. 43

Ake Gustafsson (b. 1908), a Swedish mutationist who is internationally known for his outstanding work on mutation breeding.

that only one gene in thousand may be more useful for plant breeding purposes and this one-in-thousand shot has paid great dividends in agriculture.

3. Gustafsson has also criticized that mutation breeding is only good for some specific achievements. He says that mutation breeding is as good as other methods of crop improvement or even superior to them in some cases.

4. Further, he states that the required amount of variation can be produced rapidly and economically with less investment of land and labour by mutation breeding than hybridization.

5. Lastly, Gustafsson says "Radical changes in agricultural techniques and human needs, and human prejudices as well, force the plant breeder to employ all available methods, including mutation for the improvement of cultivated plants".

Whatever may be the controversies, which are beyond the scope of this book to deal in detail, it is a fact that the mutation breeding is gaining the increased impetus with emphasis on peaceful uses of atomic energy. Every day new atomic reactors and gamma gardens are constructed for increasing the availability of more and more radioisotopes for improvement of agriculture.

LIMITATIONS

1. Mutation breeding, in absence of full information about the genotype of material, proper mutagen and its efficiency, frequency of different kinds of mutation, i.e., beneficial and non-beneficial, proper and sufficient techniques and other related phenomena and factors, is not a good device for crop improvement.

2. Mutation breeding work is confined to a few institutions where irradiation facilities and trained personnel are available. Government too can afford to grant such facilities only to a few institutions.

3. This breeding method does not produce the ready-made varieties but it creates the inexhaustible variation with greater frequency than that occurring in nature from which the desirable characters are picked up and utilized directly or indirectly. For this, one has to employ one or the other technique of conventional method and, therefore, unless sufficient resources for crop improvement by conventional breeding are available, no one can jump to mutation breeding.

ADVANTAGES

1. Mutations produce inexhaustible variations and, therefore, mutation breeding makes the plant breeders free from complete dependence on nature for raw materials, i.e., variations. Such created variations are not merely due to recombinations as is in hybridization but they are original and newly created.



Fig. 44

N. P. 836, an awned wheat variety produced from the awnless variety N.P. 799 by gamma irradiation at the I. A. R. I., New Delhi (*By courtesy of Bot. Div., I. A. R. I., New Delhi*).

2. When no improvement is possible, irrespective of whether variation is present or not, by conventional methods the only alternative is mutation breeding as has already been pointed out under its application.

3. Under special circumstances, as dealt under application, the mutation breeding has maximum utility in crop improvement.

4. Time, labour, land and expenses needed in mutation breeding are considered to be less than those incurred in conventional breeding procedures.

ACHIEVEMENTS

The mutation breeding work in India had been in progress since 1935 (Ramiah, *et al.*, 1935) and then onwards sporadic attempts were made by individual workers in ill-equipped labora-

tories haphazardly with a view to produce improved strains in different crops The establishment of Gamma Gardens at the Bose Research Institute, Calcutta in 1959 and at I. A. R. I., New Delhi in 1960, where work is in progress since 1942 and 1955 respectively, has opened a new vista in crop improvement. At present the mutation facilities are available at I. A R. I, New Delhi; the Bose Research Institute, Calcutta; the Atomic Energy Establishment, Trombay; the Tata Institute of Fundamental

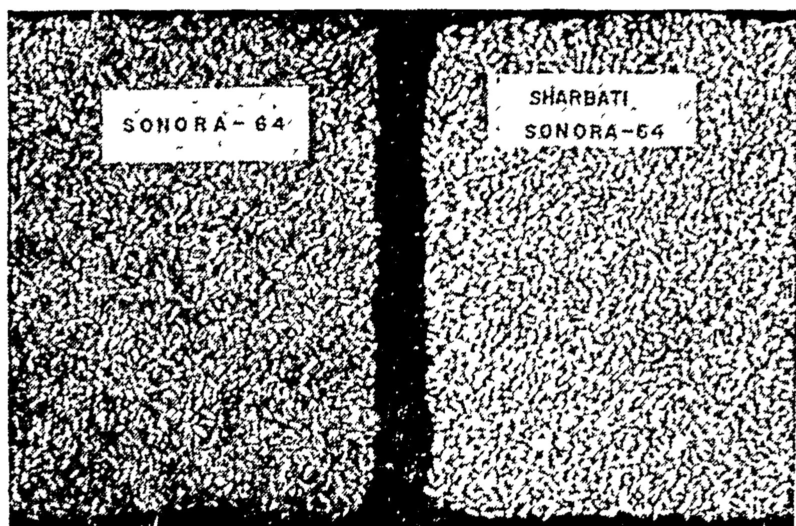


Fig. 45

Sharbati Sonora-64, an amber grained wheat variety produced from the red grained Mexican variety Sonora-64 by gamma irradiation at the I. A. R. I., New Delhi (*By courtesy of Dr. M S. Swaminathan*).

Research, Bombay, etc., where plant material can be treated and breeding may be carried out at different places in Institutions, Universities, Departments and Farms by different workers.

The workers in India so far have made efforts in different crops for the following achievements:

Table 14. The objectives for which efforts have been made by mutation breeding in crop improvement

S. No. 1	*Crops* 2	*Aims of achievement* 3
1.	Wheat	Induction of awns, increased yield, rust resistance, short and stiff straw, non-lodging and ear branching.
2.	Barley	Increased yield, malt qualities and disease resistance.
3.	Oats	Higher yield combined with late maturity, stiff straw and disease resistance.
4.	Rice	More tillering, resistance to lodging, high yield, colour mutants, response to high fertility and earliness.
5.	Sugarcane	Disease resistance and increased yield.
6.	Potato	To overcome the interspecific incompatibility.
7.	Tobacco	Increased yield and nicotin content, enhancing the rate of pollen tube growth per unit time in *Nicotiana rustica* to overcome the incompatibility relationship in the cross *N. tabaccum* × *N. rustica*.
8.	Cotton	Increased staple length, disease and insect resistance, and more yield.
9.	Mustard	Earliness, increased yield and oil content, and non-shattering quality.
10.	Tomato	Uniform red skin, increased yield, more and compact fruiting.
11.	Sesamum	Increased oil production, better keeping quality and earlier flowering.
12.	Groundnut	Increased size and shape of seeds, higher yield of oil, and disease resistance.
13.	Castor	Increased oil yield, production of 100% pistillate flowers, small and heavy seededness.
14.	Coconut	Earlier maturity of fruits.
15.	Jute	Tallness of plants and early flowering.
16.	Chrysanthemum.	Bisexuality and double flowers.
17.	*Guar*	Increased yield, profuse bearing and increased size of pods.

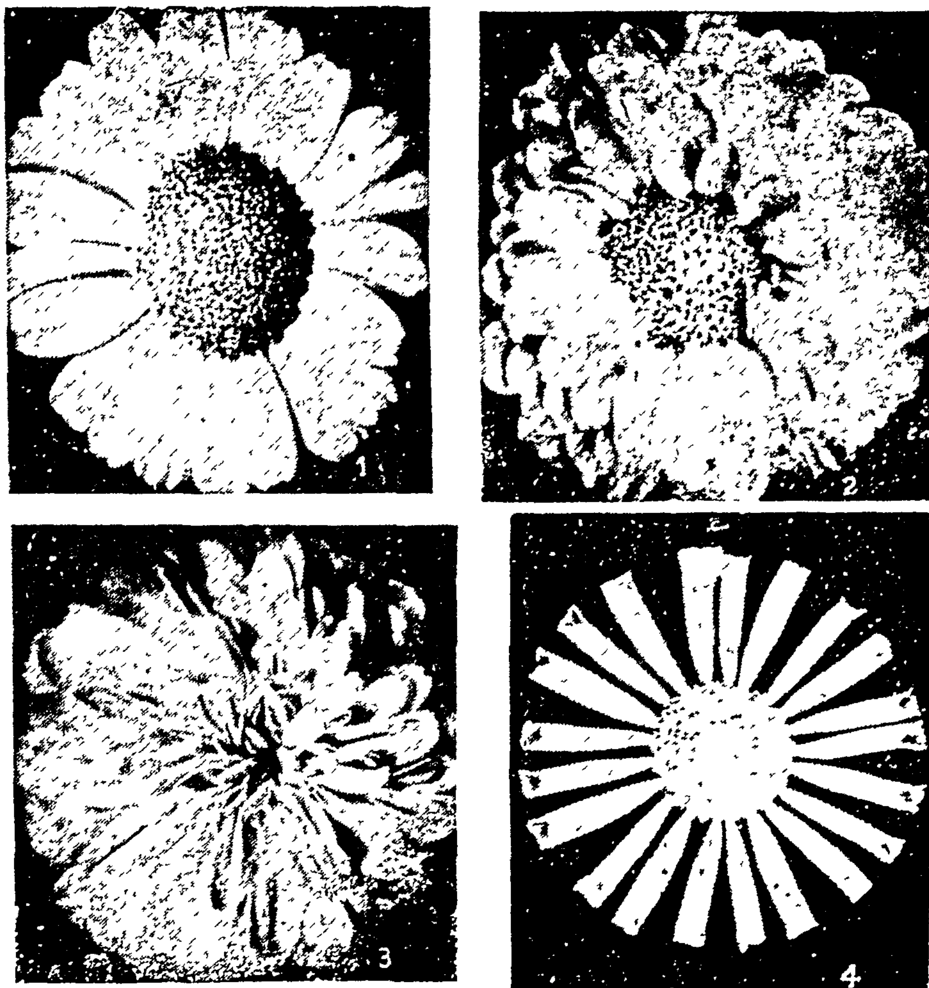


Fig. 46

Chrysanthemum : 1. Single flower of control, 2 Mutant flower of regular double type, 3. Mutant flower of compact double type, and 4 Mutant flower of tubular type (After *Ind. J. Genet. & Plt Brdg*, 1961)

Mutation breeding carried out for these achievments hase already resulted in the production of some improved strains as given on the next page:

Table 15. Varieties developed by mutation breeding

S. No.	*Crop*	*Mutant variety*	*Details*
1	2	3	4
1.	Barley (*Hordeum vulgare* L.)	Pallas	Produced in Sweden from the variety 'Bonus' (Borg, *et al*, 1958). It is high yielding and stiff-strawed.
		Mari	Produced in Sweden from the variety 'Bonus' (Gustafsson, *et al*, 1960).
		Jutta	Produced in Central Germany, from the variety Kleinwanzlebner Mittelfruhe (Mench, 1957). It is very high yielding and resistant to winter and lodging.
2.	Bean (*Phaseolus vulgaris* L.)	Sanilac	Produced in U.S.A. from the variety 'Michelite' (Down and Andersen, 1956). It is early maturing, disease resistant and bush type in growth.
3.	Cotton (*Gossypium hirsutum*)	Indore-2	Produced from the X-rayed material of Malwa Upland-4 at Plant Industry, Indore, India.

4. Groundnut (*Arachis hypogaea* L.)	NC.4X	Produced in U.S.A. with X-ray treatment from the variety NC.4 (Gregory, 1956). It is having more yield, good quality and thicker hull.
5. Jute (*Corchorus olitorius* L.)	JRO-514 JRO-412	Produced from X-ray treatment to JRO-632 at the Jute Agric. Res. Sta., Barrackpore, India.
6. Mustard (*B. juncea*)	APM (Appressed pod mutant)	Isolated in 1956 from X-3 generation of Rai 5 at the Bose Research Institute, Calcutta, India. It possesses appressed and non-lodging pods.
(*S. alba* L.)	Primex white	Selected in Sweden from X-ray treated material of Svalof's white mustard (Andersson and Olsson, 1954). It is high in oil content.
7. Oat (*Avena sativa* L.)	Florad	Produced in U.S.A. from the variety 'Floriland' (Chapman *et al*, 1961). It is early maturing, high yielding, good in quality and resistant to crown rust.
	Almo—X	Produced in U.S.A. from X-rayed material of Almo (Lewis, 1962).
8. Pea (*Pisum sativum* L.)	Stral	Produced in Sweden from the variety 'Kolster' by X-radiation (Gelin, 1955). It is high yielding and branching.
9. Rape (*B. napus* var. *oleifera*)	Regina II	Produced in Sweden from Regina (Gustafsson and Tedin, 1954). It is higher in oil content.

(*Contd.*)

1	2	3	4
3.	**Application**	Used in all types of crops and application is only possible when variation is already present. If natural variability has been exhausted, the use of conventional breeding methods has no meaning.	Used in all crops but more in self-pollinated due to easy detection of mutants. It can be used at any stage of breeding irrespective of whether variation is present or not, depending upon the problem. Its application is possible when mutation facilities and trained personnel are available.
4.	**Time and expenses spent**	Time and expenses spent are more, specially in hybridization.	In comparison to hybridization, less time and expenses are required.

Questions

1. Define the term 'mutation' and give its origin. What types of changes are included in it and give the modern concept of definition of mutation ?
2. What are the different types of mutations according to the source of their origin ? Differentiate between them. Are they fundamentally different ?
3. Discuss the use of spontaneous as well as induced mutations in plant breeding.
4. What do you mean by 'induction of mutation' and how the mutation can be produced artificially ? Discuss briefly.
5. Why gamma rays are more commonly used in plants for induction of mutations than the other mutagens ?

6. When and where the first Gamma Garden in India was opened for improvement of agriculture ?

7. When Gamma Garden of I. A. R. I., New Delhi, was started and who is its supervisor ? Is it open to every worker in the country for treatment ?

8. What are the immediate effects of high dosages of radiation in plants ? What do you mean by L.D. 50 ?

9. Why the screening of treated material is more reliable in R_2 than in R_1?

10. The effects of radiation treatment are not seen in whole of the irradiated plant population. Why? Explain the genetical cause behind it.

11. What precautions are to be taken during the procedure of mutation breeding ? Describe in brief.

12. Give the possibilities of application of mutation breeding in different types of crops.

13. Why mutation breeding has been used more in self-pollinated crops than the cross-pollinated crops ?

14. Give the conditions under which there is no alternative except to use mutation breeding for desired improvement.

15. Mutation breeding is very useful in creating the simply inherited characters like disease resistance. This can also be easily achieved by backcross method. Why, then, one has to prefer mutation breeding ?

16. Discuss the controversy over the application of mutation breeding and also give your opinion.

17. What are the main obstacles in crop improvement by mutation breeding ?

18. Cite the names of few varieties produced by mutation breeding in wheat and *sarson*

19. Differentiate between the following :
    (i) Mutation breeding and Conventional breeding.
    (ii) Irradiation breeding and Mutation breeding.
    (iii) Mutation breeding and Polyploidy breeding.
    (iv) Chromosomal mutations and Point mutations.

20. Define or describe the following terms :
Radioisotopes, Irradiation, Unit of measuring X-rays, Chairman of Gamma Garden, I. A. R. I., New Delhi, and Gamma rays.

21. List the work of following scientists for which they are famous :

(i) De Vries (ii) Swaminathan
(iii) Muller (iv) Gustafsson
(v) Stadler

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CHAPTER 11

BREEDING FOR DISEASE RESISTANCE

Diseases are the main enemies of the crops and they cause enormous loss to the agricultural production of the country. They are produced by many organisms such as fungi, viruses, bacteria, parasites, etc. These organisms attack almost all the crop plants causing various types of diseases which run about 25,000 in number.

The extent of loss and damage caused by diseases varies from year to year depending upon the prevalent climatic factors which highly influence the onset and spread of diseases. In normal year the damage is estimated to be approximately 10 to 25% or even low, while in the years of epidemics the entire crop is destroyed and thus the damage may extend up to 100% as happened in 'Tikka' epidemic of groundnut in Bombay State during 1912-13, and wheat rust epidemic of 1946-47 in Peninsular India. Although the accurate figures are not available, it is estimated that the annual loss due to plant diseases in India in terms of money runs into several hundred crores of rupees.

APPLICATION OF RESISTANCE BREEDING

Two methods, *viz.*, **phytopathological** and **resistant varieties** are available to combat the diseases in plants. The principle underlying the phytopathological measures is to prevent or eradicate the disease causing organism, i.e., pathogen and the practices adopted are field sanitation, clean cultivation, crop rotation, application of chemicals in form of spraying and dusting, hot water treatment, etc. On the other side, the principle underlying the breeding for resistant varieties is to control the disease by inducing some power within the plants themselves so that they may resist the invasion and the establishment of pathogens. The comparative merits and demerits of both the methods have been given in Table 17.

Table 17. Comparison between the phytopathological and the "resistant varieties" methods of plant disease control

S. No	*Comparison between*	*Phytopathological measures*	*Resistant varieties*
1.	**Basis of control**	The causal organisms, i.e., **pathogens** are controlled.	New **characters are brought into the plants** themselves to resist the pathogens.
2.	**Origin**	**Easily evolved** in short time with less labour and expenditure	It is **tedious** and time - consuming process to evolve new varieties **but the improvement** so obtained **is** of **permanent** nature.
3.	**Application**	**Not** possible to control **some diseases** like viruses, root-rots, rusts, etc.	**Applicable to every disease** but in some cases not advisable to use
4.	**Utility to farmers**	Laborious, time-taking and **costly to farmers**	Cheapest and most **inexpensive to farmers**

It is quite apparent that from farmers' point of view, the resistant varieties are the cheaper, convenient and better measures of disease control rather than the phytopathological methods In fact, neither the phytopathological nor the breeding measures alone can control all the plant diseases and, therefore, both the methods are in vogue Breeding for disease resistance is unavoidable in some specific categories of plant diseases such as viruses, wilts soil-borne smuts, certain nematodes and root-rots, which can not generally be controlled by the phytopathological measures or where ordinarily their application is prohibitive in cost.

Breeding for disease resistance, though a best and most effective method of controlling plant diseases, is a long-term programme and involves high technical skill and intimate knowledge of science of plant breeding, genetics and plant pathology

Good success is achieved only when the combined efforts are made by the team of experts from all these branches.

MECHANISM OF DISEASE DEVELOPMENT

Breeding of disease resistant varieties is based on the intimate knowledge of host-parasite relationship and *the better this mechanism is understood the easier is task of breeding disease resistant varieties.* In the development of disease, two organisms, pathogen and host, are involved. **Pathogen is the disease causing organism and host is the plant on which the disease develops.** Each pathogen is very specific in its host and **their relationship with each other is known as host-parasite relationship** which ultimately results in the development of disease. There are **four phases of host-parasite relationship** as given below :

(1) Contact : This phase includes the **reaching of pathogen on its host**, i.e., invasion, the extent of which is largely controlled by environmental factors.

(2) Penetration : It is the **entrance of pathogen into the tissues of host plant** and is only possible when the conditions are suitable for germination of pathogen spores in the contact phase. The penetration may take place through any of the three passages, *viz.*, cuticular or epidermal surface of the leaf and stem; natural openings such as stomata, hydathodes or lenticels; and natural or inflicted wounds. The success of penetration

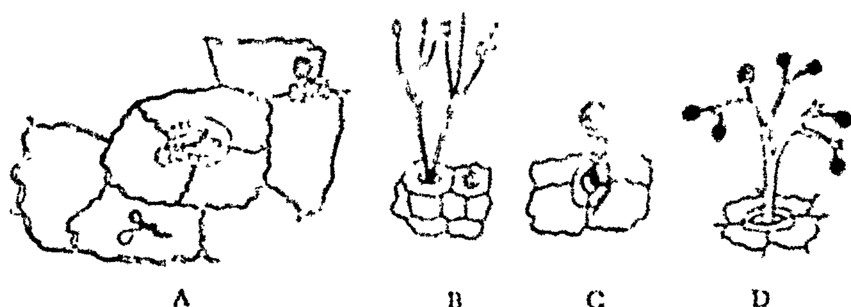


Fig. 47

Late Blight of Potato (*Phytophthora infestans*) : A. Germ tube of the pathogen entering through stomata as well as directly through epidermis, and B. Sporangiophores protuding through stomata. Downy mildew (*Peronospora parasitica*) C. Germinating spore entering through stomata, and D. Sporangiophores with sporangia coming out of stomata

depends upon the penetrating power of a pathogen and resistance power of a host. Both are the inherited traits and their expressivity is greatly affected by the environmental conditions.

(3) **Establishment** : In this stage **the pathogen reaches to the interior tissues of the host** and **establishes the parasitic relationship with them** It results only after successful penetration provided the conditions within the host are favourable Penetration may be there but if the conditions within the host are unsuitable, the pathogen will be checked and destroyed. Hence, it depends upon the resistance capacity of the host to control the establishment phase of disease development.

(4) **Development** : This is the phase which results in a disease and causes severe losses to the crop plants. In this the pathogen after establishment sucks up the nutrients from host and multiplies in number rapidly. Consequently, the disease is developed with its specific symptoms by which it is diagnosed and identified The different types of symptoms shown by plant diseases may be grouped together briefly as follows :

(i) Foliage infection causing leaf-spot, shot-hole, necrosis, chlorosis, mosaic, etc.

(ii) Transformation or destruction of plant parts, e. g., grain smut and ergot.

(iii) Hypertrophy and malformations of tissues as in crown gall of fruit trees and green ear disease of *bajra.*

(iv) Wilting as damping-off of seedlings and wilting of root and stem parts of the plant.

(v) Rotting of plant parts as in root-rots, stem-rots, fruit-rots, etc.

(vi) Dropping of leaves, blossoms, and fruits.

Each disease is the product of interaction among the host, the pathogen and the environment. In absence of any one, the occurrence of disease is made impossible. Each disease has its specific host on the availability of which it develops only under a particular set of environmental conditions among which the atmospheric temperature and relative humidity are the most important. In a year when the temperature and humidity are less favourable, the occurrence of disease is rare and it is known as *sporadic.* On the contrary, when they are highly favourable in a year the disease multiplies very rapidly and spreads severely over the entire region causing heavy losses to the crops. Such severe appearance of a disease in a particular year is known as *epidemic*

or in American terminology *'Epiphytotic'* † and can result only from the cumulative effects of all the three factors acting simultaneously.

The resistant varieties may check the pathogen at any step up to the third phase and after entering into the fourth phase only the control measure applicable is phytopathological techniques. In breeding for disease resistance, the plants are provided with such characters which would throw away the parasite up to the third stage.

NATURE OF DISEASE RESISTANCE

By the nature of disease resistance we usually mean the ways and weapons available with plants by which they can fight against the pathogen and save themselves from the attack of the these organisms These ways are three, namely, **disease escape, disease endurance or tolerance,** and **disease resistance.**

Disease escape : The ability of susceptible plants to avoid attack due to some inherent or environmental conditions, such as rapid growth and early maturity, and the change in growing period, sowing time or method of cultivation, is known as disease escape. All the conditions of disease escape, may be inherent or environmental, create unsuitable conditions for pathogen to reach on the host to develop the disease.

Early maturing varieties of groundnut escape the infection of 'Tikka disease' (*Cercospora arachidicola* Hori.). Early varieties of wheat are also known to escape heavy damage caused by rusts in those areas where the severe attack generally occurs late in the growing season. Early varieties of potato often escape the attack of late blight in regions where conditions are rarely favourable for rapid and abundant growth of the pathogen until late summer or early fall. Examples of disease escape by non-heritable characters are also many on record A change in the planting season of sugarcane, i e , October instead of June, has been successfully used as a measure of escaping leaf-rust (*Puccinia sacchari*) in the canal areas of Bombay. In ragi (*Eleusine coracana*) too the sowing of the crop in October instead of June has been found an effective control of the blast disease (*Piricularia oryzae* Cav) in the parts of

† The word epidemic is for severe occurrence of human disease and epiphytotic for plant disease but both the terms are used interchangeably by plant pathologists.

Madras State where the disease is of abundant occurrence in June In soil-borne diseases like wilts and root-rots in which the soil temperature at growing periods determines the severity of disease occurrence, a few weeks variation in sowing time may reduce the disease losses remarkably as have been reported in case of *Fusarium* wilts in Bombay and flax in Punjab. At low temperatures (18 – 20°C), where pathogens are unable to cause infection, the susceptible varieties show high resistance due to escape. Similarly a change in actual method of cultivation has also been reported to escape diseases in many cases.

The purpose of breeding early maturing varieties in different crops had been to escape the disease occurrence late in the season. All the disease escaping crop plants when exposed to artificial infection, exhibit high degree of susceptibility to the disease.

The disease escape is the first phase of disease control and it avoids the disease by overcoming the first phase of host-parasite relationship.

Disease endurance : Disease endurance or tolerance is the ability of plants to tolerate the invasion of a pathogen without showing much damage and many symptoms. Enduring plants are able to grow in spite of an attack through exceptional vigour or hardier structure which can be modified by the different methods of manuring and cultivation Thus it is brought by the influence of external characters. It is known that wheat varieties fertilized with potash and phosphorus are more tolerant to the rust and mildew infections. Likewise, the rice crop fertilized with silicates is resistant to blast infection in Japan The fertilizers in these cases arrest the vegetative growth indirectly and promote the early maturity, stiff straw and hardier tissues which tolerate the infection. It is also a cheaper method of disease control and the losses caused by infection in the enduring strains are usually negligible.

Disease resistance : The ability of plants to withstand, oppose, lessen, or overcome the attack of pathogens is known as resistance It is highly variable in amount ranging from zero to cent per cent and, therefore, the different terms such as susceptibility, resistance and immunity are used to denote the different degrees of resistance in plants (Table 18)

Table 18. Different degrees of resistance in plants

S. No.	*Degrees of resistance*	*Technical terms used*	*Stage at which operates*	*Amount of loss*
1.	Cent per cent resistance	Immunity	Resistance to contact, and no symptoms are shown by plants.	Nil
2.	High or moderate resistance	True resistance	Resistance from contact to development stage, and symptoms are developed.	Negligible
3.	Slight resistance	High susceptibility	Slight resistance is due to some morphological characters.	High
4.	Zero resistance	Cent per cent susceptibility	None	Very high or cent per cent

Immunity: Immunity means the complete resistance to diseases and the pathogens can not attack the plants possessing it.

Susceptibility · It is the inability of a plant to defend or overcome itself against the pathogen and its attack.

Wingard (1953) has stated that "the immunity is absolute and resistance and susceptibility are relative. A plant is either immune or not immune to a pathogen but it may be more or less susceptible or resistant. A plant may be slightly susceptible, moderately resistant, or extremely susceptible, but not moderately immune or highly immune". Further he has stated that no sharp distinction can be made between disease enduring and disease resitant varieties

Resistance is largely controlled by inherited characters, may be due to one or more, differing from strain to strain.

CAUSES OF DISEASE RESISTANCE

The causes of disease resistance in plants are two, i.e , **environment** and **heredity**. The environmental causes show only temporary resistance, e.g disease escape and disease endurance, whereas the hereditary causes, e.g., morphological, structural, functional and protoplasmic factors, give rise to true resistance of permanent nature.

Morphological characters: The different morphological characters responsible for disease resistance are hairs and waxes on surface, nature and thickness of cuticle, epidermis and stomata, etc. The presence of more waxes and hairs checks the pathogens to come in contact with the host and thus the resistance to first phase of disease infection is offered by them. The thick cuticle and epidermis (Fig.48) hamper the penetration of pathogen into the host tissues and thus *they offer resistance to entrance.*

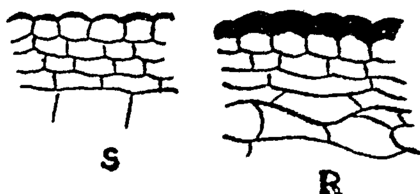


Fig 48
Morphological resistance in plants due to thickness of cuticle S-Susceptible and R-Resistance (*After Kamat, M N*, 1956).

Structural characters: They include the proportion of strengthening tissues, fibre content, the number, size and nature of stomata and lenticels, the nature of middle lamella and cork,

etc. In red-rot of sugarcane, caused by *Colletotrichum falcatum* Wint., the resistance of varieties is due to the increase in thickness of sclerenchyma around the vascular bundle. *They provide resistance to the penetration of pathogen.*

It is not always possible to distinguish clearly between the morphological and structural causes of disease resistance in plants.

Functional characters: Certain physiological characters like the number of stomata per unit area of host and time of their opening, the time of flower opening, the rate of cork formation and cambium activity cause the disease resistance in plants. In some cases stomata remain closed at the time of pathogen's penetration thus making the crop variety resistant to disease infection. This character is in operation only against those diseases in which pathogens enter mainly through the stomata. In wheat varieties, sometimes due to environmental variation, the stomata remain closed in the morning thus preventing the entry of germ tubes of rust pathogen into the host tissues. *The functional characters usually impose resistance to the entrance.*

Protoplasmic factors: The protoplasmic characters controlling disease resistance are cell contents including acids, tanins, anthocyanins, chemical constituents and their proportions, antibiotic activity, hypersensitivity, and biological antagonism of the protoplasm of host and pathogen. They may either be toxic or exert inhibitory influence on the parasite thus bringing the desired resistance to the crop plants. *The protoplasmic characters provide resistance to the entrance as well as to the establishment phase of the pathogen.*

The functional and protoplasmic factors together are also known as *physiological factors* because it is not possible to differentiate between them.

The true resistance due to the aforementioned four factors is very specific, largely determined by the defensive activities of the plant itself against the parasite, and, therefore, very less influenced by the environmental factors.

GENETICS OF DISEASE RESISTANCE

Disease resistance is a hereditary character and its behaviour is not uniform in all the cases. While **in some cases it is dominant** and **in others it is recessive. In some plants**

resistance is due to a single gene, i.e., **monogenic and in others** it is the result of interaction of many genes, i e., **polygenic** inheritance.

It is rarely found in the nature that a variety resistant to one disease is resistant to the another disease of the same crop. Sugarcane strains resistant to red-rot are highly susceptible to the leaf-rust and whip-smut. The highly rust resistant 'Khapli' wheat strain was found to be highly susceptible to *Helminthosporiun* stripe in Bombay State. It can, therefore, easily be said that the resistance to one disease is seldom synonymous with the resistance to another disease of the same crop

Another puzzling problem of disease genetics is that the genes controlling disease resistance may be closely associated with inferior agronomical characters, such as the superior types of rice '*Bhangar-kaddi*' and '*kolamba*' readily succumb to blast infection while the inferior and wild types exhibit high degree of resistance. The high yielding and good quality Indian '*Baxi*' wheats are highly susceptible while the inferior '*khapli*' is highly resistant. Similarly the superior '*Son*' variety of banana is highly susceptible to *Fusarium* wilt while the inferior '*Kali*' is highly resistant. This problem is indeed a great handicap in achieving the resistant varieties with good qualities.

A crop variety resistant to a disease in one locality may or may not be resistant to the same disease in an another locality with entirely different climate.

SOURCES OF DISEASE RESISTANCE

In all, there are two sources from where the genes for disease resistance can be obtained and utilized:

(1) Already existing plant material possessing the genes for disease resistance, and

(2) Mutations by which genes for disease resistance are newly created.

The resistance already existing may be present either in the varieties of same species or in the varieties of other related species. Again in them it may be present either in the cultivated species or in the wild species. It is of more common occurrence in the later type than in the cultivated forms. The resistance found in the cultivated strains within the same species is always

more beneficial than that found in wild strains because it can be easily transferred into the needed strain through hybridization. Irrespective of its presence in closely or distantly related species, the resistance may be found in the material available even in the country or in another country from where it can be introduced. For this reason, a collection of resistant material of different crops must be maintained from all over the world so that it can be utilized at the time of need.

Sometimes, however, the resistance is not found in the already existing plant material or even if found it is either inadequate or unattainable due to some limitation, and, therefore, one has to turn to mutations in which attempts are made to induce the resistance artificially by the application of mutagenic agents.

METHODS OF BREEDING FOR DISEASE RESISTANCE

The methods used in breeding resistant varieties are same as those used in breeding for other characters except one important difference, i. e., instead of one, two organisms, *viz.*, pathogen and host, are involved. This difference causes no change in the methods to be applied but simply alters the steps involved in the procedure of breeding. The various methods used for developing disease resistant varieties are :

(1) Introduction,
(2) Selection,
(3) Hybridization,
(4) Budding or grafting, and
(5) Mutation breeding.

Introduction: Disease resistance is an inherent character found scattered in different varieties of the crop all over the world. A very simple and inexpensive way is, therefore, to make direct introduction of such variation into a region where the specific disease is found in epiphytotic form. For instance, the early maturing varieties of groundnut introduced from U. S. A. have successfully conquered the problem of 'Tikka' (*Cercospora arachidicola*) in India. The 'Ridley' wheat variety from Australia and POJ canes from Java are also the examples of introductions. The cases of such direct introductions are, however, very few on record.

While theoretically the direct introduction of resistant varieties seems to be a very simple method, unfortunately in practice it has been found full of difficulties enumerated as follows :

(i) The acclimatization of the introduced varieties has been found unsuccessful in most of the cases

(ii) The introduced varieties possessing resistance to one disease become susceptible to another disease, as for example, the wilt resistant American cotton varieties introduced into India became highly susceptible to red blight and Kenya wheat varieties bacame susceptible to loose smut.

On account of these limitations, the introduction can not be considered as a common method for producing disease resistant varieties

Selection : This is the better method than the introduction and has more chances of success in obtaining the disease resistant varieties It is practised both in introduced as well as in local commercial varieties. In beginning the material is grown in field and the resistant plants are selected. In subsequent years the material is grown either in field or special glass houses with susceptible variety and the planting is done either in mass or in progeny rows depending upon the type of selection to be practised for picking up the desired plants. Since natural disease epidemic may not occur every year or if occurs the resistance shown by plants may be due to escape, not due to true resistance, it is, always essential to create the disease epidemic by artificial means, so that the resistant plants can be distinguished from the susceptibles to facilitate their selection For creating the artificial epidemic, the crop plants are provided with pathogen artificially by different techniques known as artificial inoculation techniques and the optimum conditions are created around the plants, so that the pathogens may develop and spread in the field causing the disease epidemic. For providing the optimum conditions, inoculation tents (Fig. 49) are erected over segments of field plots and plants under them are regularly sprinkled with water from time to time to maintain an optimum relative humidity and temperature. If it is not always possible to provide the optimum conditions in the field for the disease development throughout the crop period, the cultures should be grown simultaneously either in the glass-

houses or greenhouses (Fig. 50) in which the humidity and temperature can be controlled with reasonable precision.



Fig. 49
Muslin Canopy method of creating artificial rust epidemic in linseed field (*After Ind. J. Gent & Plt. Brdg*, 1950).

Inoculation technique for soil-borne diseases : The diseases like wilts, root-rots and seedling-off are caused by soil-borne pathogens that enter the host plant through the roots or other underground parts. For artificial epidemic of such diseases the varieties are grown in soils which contain the needed pathogens Sometimes, if the disease development is less, its intensity can be increased by spreading the soil collected from other diseased field over test plot, or the plot soil is inoculated with cultures of causal organism grown on sterile grains or on other types of nutrient media. The same soil is used again in succeeding years. In greenhouse the inoculation is done by growing the varieties in pots or containers with inoculated soil or culture.



Fig. 50
Glasshouse tests for varietal resistance to blast in rice under artificial infection (*After Kamat, M. N*, 1956)

Inoculation technique for air-borne diseases : The diseases like rusts, smuts and spots are developed by air-borne pathogens which

enter into the host through stomata, lenticels and wounds. The inoculation technique in these diseases varies from dusting spores on leaves to spraying the plants with spore suspension. Sometimes, the pathogens are inoculated by using a hypodermic needle to inject a spore suspension into the plants. (Fig. 51).

Inoculation technique for seed-borne diseases: Some diseases like smuts and bunts are seed-borne and the inoculation in them is done by applying the spores to the dry seeds before planting or by soaking the seeds in spore suspension under vacuum.

Inoculation technique for fruit diseases: Certain diseases like loose smut of wheat and barley are developed by spores from smutted plants. The spores are either put by forcep on the floral parts or spore suspension is injected.

The inoculation techniques and the ways of creating optimum conditions for disease development are same in all the methods of breeding for disease resistance.

The plants found resistant are picked up They are similarly grown and subjected to intensive tests over several years during different seasons. If in any tests and in any one season the selected resistant plants succumb to the diseases, they are rejected straight way. The plants which prove resistant in all the tests are further tested under different meteorological and geographical conditions in various tracts suited for the cultivation of crop and their resistance to diseases is observed over a period of years. Only after these tests the variety is given name, either immune or resistant as the case may be.



Fig 51

Method of inoculating rust spores into the wheat seedling in the field.

The close association, often found between the resistance and inferior agronomic traits in plants, is the main obstacle which can hardly be overcome by selection in naturally variable material and, therefore,

this method too is not efficient to meet the requirement of disease resistant varieties.

Hybridization : This method is the only effective way to combine good features of two varieties together into one. When the adequate resistance is not found in the commercial varieties but only in undesirable inferior ones which can not be used commercially because of their inferior qualities, the hybridization is used to incorporate the resistance with good qualities in commercial strains.

In a hybridization procedure either the backcross or pedigree method of breeding is usually used. In both methods, one parent is chosen for its good agronomical qualities and the other parent is taken for its high level of resistance to a maximum number of disease races controlled by the minimum number of genes. If the resistant parent is totally unadapted and undesireable, the backcross is used as a breeding procedure. If, on the other hand, the resistant parent is equally good in qualities, the pedigree or bulk method of tackling the segregating generations may be used.

BACKCROSS METHOD : This method was used for the first time by Briggs (1930) as a means of adding disease resistance to wheat and barley varieties at California and defined as 'the crossing of recurrent parent repeatedly with hybrid progeny for the purpose of recovering its characters, except the addition of disease resistance from the non-recurrent parent'. The ease with which this method can be carried out depends upon whether the character to be transferred is **oligogenic** or **polygenic**, and dominant or recessive.

The backcross technique is very simple in the case when the disease resistance is dependent on a single dominant gene. If this gene is denoted as 'RR' the hybrids from backross to the parent 'rr' will consist of plants with the genetical constitution 'Rr' and 'rr'. The 'Rr' plants can be easily picked up and used as the hybrid parent in the subsequent backcross generations. The genetical explanation of the whole procedure has been given in Fig. 52.

During backcrossing only the 'Rr' plants are backcrossed to variety "A" and all the rest on which has been put the "t" are

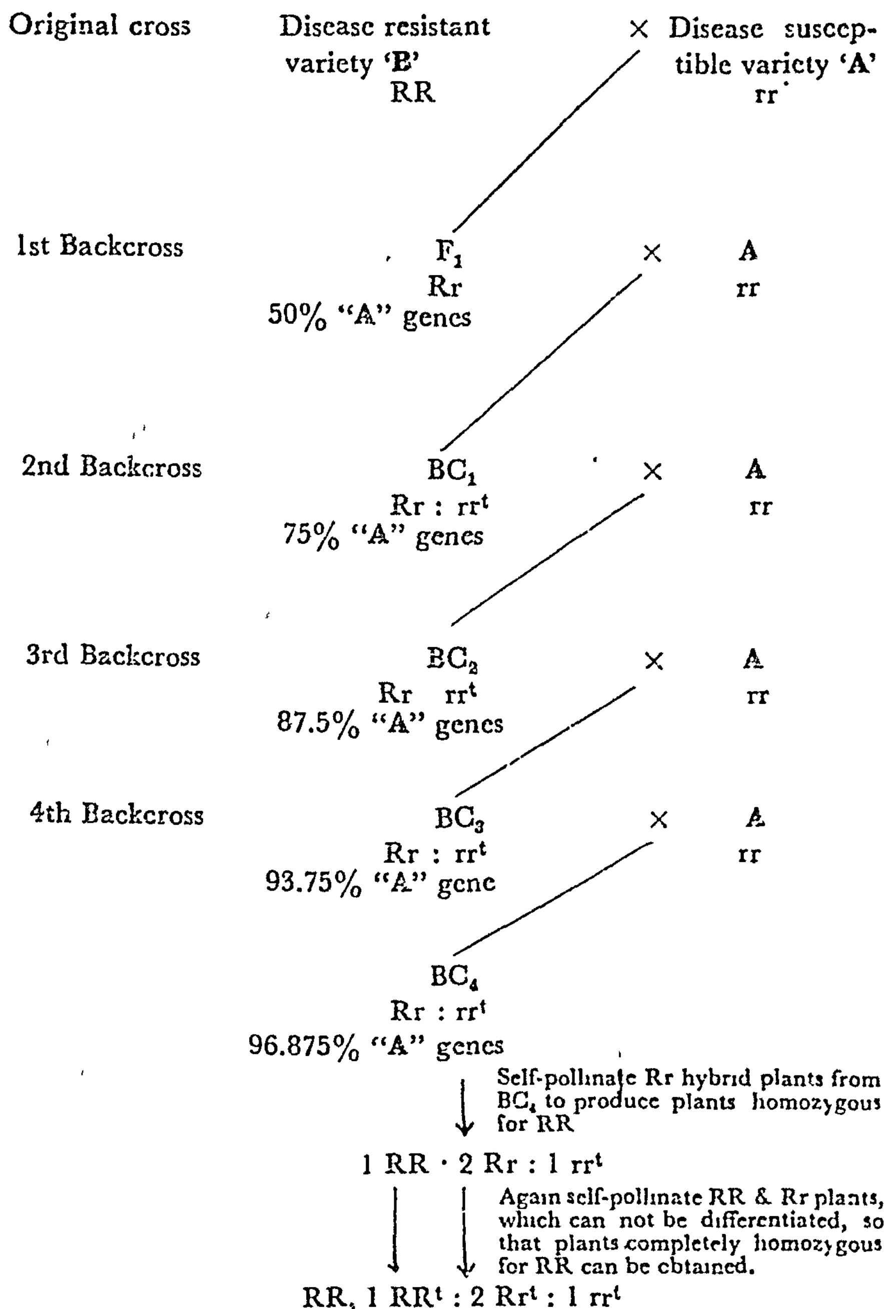


Fig. 52

Genetics of backcrossing in case of a single dominant character for disease resistance.

discarded. 'Rr' plants are identified from 'rr' by artificial inoculation of the plants with disease pathogens.

In this case the variety '**A**' has been used as the **recurrent, recipient** or **backcross parent** that contains all the superior qualities which the breeder wants to recover in the new variety. With each successive backcross the hybrids become more and more like the '**A**' in agronomical characters with an addition of one new character of disease resistance. Thus, backcross method is a sort of inbreeding except the addition of disease resistant character contributed by the **non-recurrent, i.e., donor parent.** The F_1 will be heterozygous for disease resistance (Rr) and when it is backcrossed with recurrent parent (rr), the progeny will segregate in two types (Rr and rr) for disease resistance The (Rr) plants, which are heterozygous as well as disease resistant, can be identified from the susceptible plants by the artificial inoculation of all plants with disease pathogens as given under selection of this chapter. Only the plants found resistant to the disease during these tests are then backcrossed to the recurrent parent. As many backcrosses may be made as are needed for obtaining the plants that appear phenotypically and genotypically exactly like the variety '**A**' except with an extra trait of disease resistance. This may require as many as six to eight backcrosses. The disease resistant plants selected from the final backcross will be heterozygous (Rr) for disease resistance and, therefore, they must be selfed for two generations to bring the homozygosity for disease resistance and to obtain the true breeding resistant plants (RR).

When the disease resistant character being transferred is recessive, the progeny from each backcross would segregate into two genotypes (RR and Rr) in which the heterozygotes (Rr) can not be identified from the double dominants (RR). This difficulty is overcome by selfing which is either performed simultaneously or done in alternate succession with backcrosses and which one is advisable depends upon the convenience in handling the plants In the former case, both the homozygous (RR) and heterozygous (Rr) plants are backcrossed to the recurrent parent. At the same time each plant is selfed and the selfed progenies are tested for disease resistance The backcross progenies from the plants, which exhibit heterozygosity for disease resistant, are kept and all others are discarded. In the later case, where backcrosses can not be

made until the constitution of hybrids is determined, the selfing and backcrossing are carried out in alternate seasons. The selfing is done first and then those selfed progenies which segregate are backcrossed to the recurrent parent. This procedure takes more time than the former and the principle of backcrossing is the same in both the procedures. In dominant character for disease resistance the ratio between resistant and susceptible plants of backcross progeny is usually 1 : 1 whereas in the case of recessive trait, it is complicated. This ratio is very helpful to identify whether the disease resistance is controlled by dominant or recessive gene.

The backcross hybrids are heterozygous for the disease resistance character transferred from non-recurrent parent. In sexually propagated crops it is essential to attain homozygosity to maintain the variety. In self-pollinated crops, where disease resistance is dominant trait, the object is achieved by selfing for one or two generations at the end of backcrossing and selecting the true breeding lines. If the disease resistant character is recessive, the homozygotes are recognizable without selfing the second time. In the cross-pollinated crops, the heterozygous backcross hybrids are crossed among themselves and the homozygous lines are recognized by the fact that they do not segregate in the crosses with the double crosses.

The number of backcrosses to be carried out varies from 3 to 10, and depends upon the genetics of disease resistance and the similarity between the genotypes of both parents entering into a backcross programme. Ideally it may be continued till the genetic constitution of hybrids is identical with that of recurrent parent except for one gene incorporated into them from the donor parent When the original cross is interspecific it is necessary to make relatively a large number of backcrosses so that practically all the undesirable genes of the donor parent except disease resistance may be eliminated. In the backcrossing of the closely related varieties many genes are common and, therefore, there is very little need to eliminate the characters of the donor parent. Sometimes, only one or two backcrosses are needed to achieve the goal. Briggs used 5 to 6 backcrosses most frequently.

If two or more characters are to be transferred from the undesirable (donor parent) to a desirable variety (recurrent parent),

separate backcross procedure should be adopted for each character and then the backcross derived lines from each may be finally brought together into one line by intercrossing them (convergent improvement). If the disease resistance character is polygenically inherited, the plant breeder should select from first cross the plant exhibiting maximum effect of the character needed for further backcrossing.

BACKCROSS PROCEDURE: Suppose the variety 'A' is commercially superior but disease susceptible and the variety 'B' is disease resistant but very poor in all other qualities. It is needed to transfer the disease resistance from B to A without any loss in its good characters. B is then donor or non-recurrent parent and A is recipient or recurrent parent. The steps involved in backcross procedure of these two varieties are outlined briefly as follows:

First year: Cross the selected plants of A with B, A as female and B as male.

Second year: Grow 5 to 10 F_1 (A×B) plants. Note the plants possessing desired character of A with disease resistance of B. Backcross the F_1 to A, F_1 as female and A as male and this is called backcross first abbreviated as BC_1. Collect the seeds of crossed plants and keep them separately.

Third year: Grow BC_1 generation and inoculate the plants with disease artificially. Select 10 to 20 disease resistant plants from BC_1 and backcross them to A. Collect the seeds and keep them separately.

Fourth year: Grow BC_2 plants and inoculate them artificially with disease. Select 30 to 50 resistant plants and backcross to A.

Fifth year: Grow BC_3 and inoculate artificially with disease. Select 30 to 50 resistant plants and backcross them to A.

Sixth year: Grow BC_4 and inoculate the plant population with disease artificially. Select 30 to 50 resistant plants and backcross them to A.

Seveth year: Grow BC_5 and inoculate the plants with disease artificially. Select 30 to 50 disease resistant plants and backcross them to A.

Eighth year : Grow BC_6 and inoculate the plants with the disease artificially. Select 400 to 500 resistant plants for raising the next generation.

Ninth year : Grow all the selected plants in separate rows. Select 100 to 200 rows in which plants seem to be homozygous for resistance to the disease in question and exhibit uniformity with variety 'A'. Harvest and composite the seed.

Tenth year : Grow the selected seeds by the side of A and compare the plants with it and note whether the backcross-selected plants are similar to A in all respects except disease resistance or not. If found similar to A, start multiplying the seeds and distribute to farmers.

Grafting : Hybridization is not applicable where sexual propagation is not possible, such as in vegetatively propagated crops. In them the disease resistant strains may be grafted on the susceptible plants. This is usually applied in horticultural crops and fruit trees where vegetative propagation is frequently used for multiplication and reproduction.

Mutation breeding : In the absence of resistant genes in commercial as well as already existing varieties, none of the aforementioned methods can be used for breeding disease resistant varieties. Sometimes, even if resistance gene is already existing, it cannot be utilized due to limitations in crossing and desirable qualities. Under these situations the only alternative for breeding resistant varieties is mutation thereby genes for disease resistance are newly created and utilized in mutation breeding to constitute a new strain resistance to the desired disease. The details of mutation breeding procedure have been given elsewhere in this book and, therefore, the readers are advised to read the same in continuation here.

PRECAUTIONS

The breeding for disease resistance can not be carried on successfully till all the precautions are paid full attention during the production of new strains and some of these precautions are given below :

(1) Breeding for disease resistant strains in crop must be carried out in the region where the crop in question is grown commonly and is taken on commercial scale.

(2) The plant breeder must have a thorough knowledge of all the existing varieties of the crop, may be wild or cultivated, and a collection of them must be maintained. A knowledge of the linkage in between different characters of these plants is of great help for breeding resistant varieties.

(3) The plant breeder must have a thorough knowledge of the disease and of all the physiological races of its causal organism which constantly remain arising in the nature due to hybridization, heterocaryosis, parasexuality or mutation. It is also equally important to have a thorough knowledge of the genetics of both host and parasite and their relationship with each other.

(4) During breeding, each backcross generation must be subjected to disease epidemic artificially so that the resistant and susceptible plants can be differentiated easily.

(5) The breeding must be carried out to develop resistant varieties to all the prevalent races of the disease in the locality. Now-a-days the trend has become to develop resistant varieties even to those races which are not highly prevalent in the locality at present.

Thus, breeding for disease resistance is a continuous and arduous task requiring patience and persistence.



Fig. 53

Pusa Sawani Bhindi, resistant to yellow mosaic disease of *Bhindi* (*After Ind. J. Genet. & Plt. Brdg.*, 1960).

Table No. 19. Varieties of various crops resistant to different diseases

S. No. 1	*Crop* 2	*Resistant varieties* 3	*Disease to which resistant* 4	*Locality in which grown* 5
1	Wheat	N. P. 783	Brown rust (*Puccinia triticina* Erikss.)	
		N P. 784		
		N. P 785	Yellow rust (*Puccinia glumarum* Erikss and Henn.)	
		N. P. 786		
		N. P 789	Black rust	U. P. Bihar and M. P.
		N P. 790	(*P graminis tritici* Erikss. and Henn.)	
		N P 809	All the three rusts of wheat	H. P. and U. P. hills
		N P 710	Loose smut	Punjab, H.P., Raj.,
		N. P 718	(*Ustilago tritici* Pers.)	Bihar, and West Bengal
2	Rice	Co 25	Blast (*Piricularia oryzae* Cav.)	Tamil Nadu
		Co. 26		
		Hybrid Kashmere 60, M 42.		

(*Contd.*)

1	2	3	4	5
		Co. 24, T. 141	*Helminthosporium* disease	Tamil Nadu
3.	Linseed	RR 10, RR 38, RR 40, RR 45, RR 197, RR 236, RR 267 and RR 272,	Rust (*Melampsora lini* Pers Lev.)	In different states of the country
		K. 1 and K. 2	Wilt (*Fusarium oxyporum* f. *Lini* B olley).	Punjab
4.	Sugarcane	Co. 419, Co. 421, Co. 356, Co. 393, Co. 453, Co. 508, Co. 527, Co. S. 109, Co. K. 30 B.O.10, and B.O.11	Red rot	In almost all the sugarcane growing states
		Co. S. 245, Co S. 254, Co. 290, Co. 449 and Co. 617	Wilt Smut (*Ustilago scitaminea* Syd.)	Tamil Nadu
		Co. 214, Co. 315 and POJ. 2878	Mosaic	Tamil Nadu
5.	Cotton	Suyog, Vijay, Kalyan, Virnar, Jarila, H. 420. Jayawant Jayadhar & L. S. S. Varieties	Wilt (*Fusarium vasinifactum* Atk.)	Gujarat and Maharashtra region

1	2	3	4	5
6.	Groundnut	Kanpur No. 23, M. 20/38, A. H. 45 (H. G. I.)	Tikka (*Cercospora personata* B. and C.)	Kanpur and Tamil Nadu State
7.	Gram	G. 17 and G. 24	Wilt (*Fusarium orthoceras* var. *ciceri* Pad.)	U. P.
		C. 1234 and C. 235	Blight (*Mycosphaerella rabiei* Kov)	Punjab
8.	*Bhindi*	Safal Pusa Sawani	Virus Mosaic	Throughout the country.
9.	Banana	Basrai	Wilt (*F. Oxysporum* f. *vasinifactum* Atk.)	Maharashtra
10.	Lathyrus	Indore T. 12	Wilt (*F: Ortharus* var. *lathyri*)	M. P.
11.	Barley	Prior	Molya	Rajasthan
12.	Chillies	Puri red Puri orange	Mosaic	Delhi
13.	Coffee	Kent's hybrid	Leaf diseases	South India

LIMITATIONS

It is evident from the foregoing description that many difficulties are encountered during the breeding for disease resistance and most important of these are as follows :

(1) Linkage of resistant genes with the genes of inferior qualities.
(2) Occurrence of physiological races of varying capacities in the causal organism.
(3) Self-sterility in the host plant.
(4) Strictly local aspects of requirement.

Advantages

The use of resistant cultivars and hybrids for disease control has several advantages.

(1) It helps us to reduce or prevent the great losses caused by various plant pathogens and pests.
(2) It lessens the high cost of disease and pest control.
(3) It helps to avoid or diminish hazards to human health and wildlife caused by present-day large scale use of dangerous fungicides and pesticides.
(4) It also reduces the danger of air, soil and water pollution with poisonous chemicals and their residues.
(5) It impedes epidemics of pathogens and pests, and thus helps in maintaining the biological balance in a man-made environment.
(6) It is only the method available to control some highly specialized diseases like wilts, root-rots, rusts, soil-borne smuts and certain nematodes.
(7) From farmers' point of view, it is the best, cheapest and easiest method of disease and pest control.

ACHIEVEMENTS

In India, the resistant strains to most of diseases have been produced in every crop under cultivation. Some of such outstanding commercial varieties resistant to different diseases have been given in Table 19.

Breeding of resistant strains for other diseases is under investigation and it is expected that sooner or later resistant strains to every disease will be produced and available to combat their menace.

Questions

1. How the crop diseases can be controlled ? Make a comparison between different control measures.
2. State some common diseases in which the breeding of resistant varieties is unavoidable if they are to be controlled at all.
3. Discuss the phases of disease development and describe the factors controlling each phase.
4. How the study of host-parasite relationship is essential for breeding the varieties resistant to diseases ? Is it possible to control the disease by resistant varieties after entering into the fourth phase successfully ?
5. Suppose a disease has been developed and established with symptoms Which control measure can be advised to a farmer under this condition ?
6. Describe the factors controlling the disease development in plants in order of their merit.
7. Why the disease in some years is sporadic and in some years it is epiphytotic ? Discuss the causes.
8. What do you mean by 'nature of disease resistance'? Name the ways and weapons available with plants by which they can fight against their enemies, i.e., diseases.
9. Define the 'disease escape' and write down the factors governing it.
10. Describe the different problems of disease resistance in plants.
11. Enumerate the different causes of disease resistance briefly.
12. What are the sources of disease resistance and which source has been the basis of breeding resistant varieties by conventional breeding methods ?
13. What methods are available for producing disease resistant varieties and discuss the limitations of each ?
14. Which method of breeding for disease resistance is used in vegetatively propagated crops and why ?
15. Suppose a variety is commercially good but is highly susceptible to a disease. Which method of breeding will be used to bring disease resistance into this variety ? Discuss its genetic basis.

16. Describe the precautions and discuss the limitations of breeding for disease resistance.
17. Mention the varieties of diffeient crops resistant to the following diseases :
Black rust of wheat, Yellow and Brown rust of wheat, All the three rusts together in wheat, Blast of rice, Rust of linseed. Red-rot of sugarcane, Wilt of cotton, Tikka of groundnut, and Yellow mosaic of *bhindi.*
18. Define or describe the following terms :
Pathogen, Degrees of resistance, Monogenic inheritance, Backcross, Inoculation techniques in air-borne diseases, Non-recurrent parent, and Susceptibility.
19. Differentiate between the following :
Sporadic and Epidemic, Escape and Resistance, Immunity and Klendusity, and Recurrent and Non-recurrent parent.

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CHAPTER 12

IMPROVED SEED—ITS PRODUCTION, MULTIPLICATION, DISTRIBUTION, MAINTENANCE AND TESTING

An improved seed is the easiest and cheapest means among all the technical measures by which the crop production can be increased in the country. Technically the seed is a ripened ovule of the ovary but it is not necessarily an improved seed. What is then the improved seed, can not be defined in a single sentence but it is judged by its characters determined by both genetical and physical features. The **genetical factor** means the improved variety and the **physical factor** means superior quality. Hence **an improved seed is that which is of an improved variety and also of superior quality.**

The genetical requirements, i e , **the prerequisites of an improved variety** are as follows :

(1) *High yield*: At least 10 to 15% higher than the local or currently used varieties.

(2) *Wider adaptability* · The improved variety must be adapted to a wider range of locality, soil and climatic conditions than the local ones.

(3) *Proper maturity*. Suitable period of maturity according to agro-climatic conditions of the region.

(4) *Resistance to* diseases and pests, and other adverse conditions of environment such as drought, flood, waterlogging, salinity and alkalinity

(5) *High response to better conditions of growth* . Such as interculture, hoeing, weeding, manuring and irrigation.

(6) *High in nutrition and good in taste*, so that it may be accepted by consumers and can meet the market's requirements.

The seeds from a variety possessing the above mentioned characters are not only considered as the improved seeds but they must also be pure in physical qualities

The physical requirements, i.e., **the prerequisites of a superior quality** of an improved variety are as follows:

(1) *High in purity*: Free from admixtures such as inert matter, damaged and broken seeds, weed seeds, other crop seeds, etc.

(2) *Good germination*: At least 90%, i.e., higher germination percentage than the local strains of the crop.

(3) *Optimum moisture content*: Neither too less which may cause the loss of seed life nor too high which may spoil the seed by insect attack, fungus development and rotting.

(4) *Uniformity*: Uniformity of seeds in shape, size, weight and colour. Besides this, they must be of proper shape, size, weight and colour.

(5) *Disease and insect free*: The seeds must be free from seed-borne diseases and insects.

Any seed possessing these superior qualities is called as the improved seed.

PRODUCTION

The different steps involved in the production of an improved variety are given below:

Place of production: In India, the work of improvement of crops and production of new varieties is carried out by the **Central and State Agricultural Research Institutes and Departments.** In many foreign countries, where farmers are highly educated and well trained in recent techniques of plant breeding, the breeding work is also carried out on private farms; but in India it is seldom carried out on private farms except on some horticultural gardens and orchards which are under private posssesion. On these private concerns too, the work done is negligible and, therefore, it can not meet the requirement on large scale.

Workers concerned: The whole work of crop improvement and production of new varieties in India is done by **plant breeders, agronomists and horticulturists.** The plant breeders, who are also known as Economic Botanists, play the main role while the agronomists assist in plantation and trials, and the horticulturists in propagation.

Methods of production : The different methods employed by the plant breeders to evolve new crop varieties are : (1) **selection**—mass, pure-line or clonal, (2) **hybridization**, (3) **plant introduction and acclimatization**, and (4) **mutation breeding**. These methods have already been dealt in details in preceding chapters and, therefore, no need to repeat them again here.

Trials : After production the variety is tested for adaptability in the area concerned by means of trials which are conducted according to the scattered block system. The trial should contain the plots of local as well as suggested varieties but the number of varieties including the local should not exceed three in each trial. All the three varieties should be grown in contiguous plots after randomization and the size of each plot for each separate variety should be the same. The area of each plot is kept 1/80 acre for paddy and 1/40 acre for other crops.

The whole work of trial for continuous three years is carried out under the strict vigilance of technical staff, specially the Research Assistants assisted by V.L.Ws.

Naming of a new variety : When a newly produced variety is found suitable for recommending to an area, it is given a permanent name before release. The name is selected by the concerned producer, i.e., plant breeder, agronomist or horticulturist and this name is approved by the Central Variety Release Committee of I.C.A.R., New Delhi usually without any change. The purpose of giving a name to a variety is to facilitate its identification during handling at different stages of its use.

While giving the name to a variety, the following principles are taken into consideration :

(1) As far as possible a variety should be given single name and not the duplicate names.

(2) As far as possible the name should be short, specially one word name.

(3) The name should be such which may not exactly match the names of other varieties of the same crop or other crops.

The name of a variety is made up of two parts, i.e., alphabet and figure. The alphabet indicates the place of origin, quality or breeder and is given in the following way :

(1) On the basis of the place of origin, e.g., N.P. 4, i.e., New Pusa 4, R.S. 31-1, i.e., Rajasthan 31-1, etc., in wheat; Co. 312, i.e., Coimbatore 312 in sugarcane and Hr. 19, i.e., Hyderabad 19 in paddy.

(2) On the basis of method of production, e.g., S. 530, i.e., Selection 530 in *bajra*; Hyb. 38, i.e., Hybrid 38 in wheat; H.G. 7, i.e., Hybrid groundnut in groundnut, etc.

(3) On the basis of its quality, e.g., SR. 26-B, i.e., salt resistant 26 Behar and FR. 43-B, i.e., flood resistant 43 Behar in rice, Pusa Red Plum in tomato, Pusa Moti in *bajra*; Pusa Safal Sawani in *bhindi*; and Durgapura safed in *guar*.

(4) On the basis of popular names, e.g., Vijay, Digvijay, Devitej, Laxmi, etc. in cotton, Kisan, Jawahar etc. in maize.

(5) On the basis of the name of worker, e.g., L S.S., i.e., Labh Singh Selection varieties in cotton.

The figure indicates the number of pedigree reference given and used by the crop breeder. This figure in the beginning is given according to convenience and whichever is found suitable, the same is kept as such so that it may facilitate the breeder in maintaining the pedigree of it for future.

Release of an improved variety: The variety so produced is released after the approval by the Central Variety Release Committee of I. C. A. R., New Delhi. This committee was established in 1964 and is entrusted with the release of improved varieties of crops for the farmers and to keep the record of all promising varieties developed in the country. The plant breeder submits all the information regarding variety's characteristics, performance, use, seed stocks, method of multiplication, distribution and maintenance to the committee as the basis for its decision. A model schedule of information to be submitted to this committee is given in Table 20.

Table 20. Proforma for a schedule of information on improved crop variety

(i) IDENTIFICATION

a. Latin name

b. Variety name

c. Local name

d. Name approved by the Central Varieties Release Committee

(ii) ORIGIN

Name of the Research Station concerned in the evolution and release of the variety.

(iii) GENETIC SOURCE

a. Introduction

b. Selection

c Hybrid, or

d. Mutant

(iv) MORPHOLOGY

a Plant

1. Height (cms.)
2. Growth habit
3. Stem
4. Leaf
5. Flower
6. Fruit

b. Seed

1. Colour
2. Shape
3. Size
4. Weight of 1,000 seeds
5. Numbers per fruit
6. Period of viability
7. Percentage of germination
8. Crop duration, i e., duration from sowing to harvest

(v) CULTURE

a. Soil-range of adaptability

b. Cultivation

1. Season—*Kharif* or *Rabi*
2. Nursery—Planting time and method
3. Field sowing

(i) Whether irrigated or not
(ii) Seed rate
(iii) Method of sowing

(vi) RESISTANCE
a. Frost
b. Drought
c. Adverse wheather
d. Waterlogging and floods
e. Salinity and alkalinity
f. Diseases
g. Pests

(vii) YIELD AND QUALITY
a. Yield
1. Grain
2. Fodder
b. Grain—Nutritive value for human being and live-stock.
c. Fodder
1. Nutritive value
2. Palatability
d. Percentage of chemical composition in grain
1. Protein
2. Carbohydrates
3. Oil
e. Toxicity

(viii) INDUSTRIAL POTENTIALITIES
a. Textile
b. Oil
c. Others

(*After Chalam and Neelakantan with some modifications*)

This description is provided by the breeder to every seed multiplication agency which wants to multiply its seeds for distribution. This description helps in multiplication and maintenance of the variety and its identity.

MULTIPLICATION

The production of an improved variety has no meaning and value unless its seeds are increased and made available to the

farmers in adequate quantity at the desired time all over the country. The initial amount of pure seed of an improved variety available with plant breeder is very small to meet the farmers' demand and, therefore, it is multiplied through different stages of multiplication. The main purpose of this multiplication is to increase the amount of seed of newly bred variety without any loss in its qualities that have been built into it after many years of painstaking research.

Distances of isolation : The cross-pollinated and self-pollinated crops show difference in their sexual behaviour and, therefore, the distances of isolation given between the two varieties of the same crop vary in different crops. The minimum safe distance of isolation between any two varieties in different types of crops is furnished below :

Normally self-pollinated crops	. 150 cms.
Often or partially cross-pollinated crops	30 metres
Normally cross-pollinated crops	150 metres

The maize is highly cross-pollinated crop and the distances recommended are 180 metres for single crosses and 270 metres for double crosses.

Stages of multiplication : These distances are maintained throughout all the stages of seed multiplication. The pure seed is multiplied many times and then it becomes sufficient to meet the desired requirements of farmers. For this it is multiplied many times as follows :

(1) *Nucleus seed :* This is the initial amount of pure seed of an improved variety available with the concerned plant breeder. It is always cent per cent pure, genetically as well as physically, and is very limited in quantity It is produced under the direct supervision of the plant breeder at the main breeding station.

(2) *Breeder's stock seed .* This is the seed obtained from the progeny of nucleus seed. It is also produced under strict supervision of concerned plant breeder at the main breeding station and is cent per cent pure genetically and physically.

(3) *Foundation seed :* This is the name given to the seed obtained from the seed multiplication farms Any seed which is produced on Government Multiplication Farms is usually called

as foundation seed irrespective of whether it has been produced directly from nucleus seed or breeder's stock seed. It is not so pure as is nucleus or breeder's stock seed. Its production is carried out under the supervision of research assistants.

(4) *Registered seed :* This is the name given to the seed raised from progeny of any one of three aforementioned categories of seed multiplication. The registered growers are selected from the progressive educated farmers and are entrusted with the work of seed multiplication. They are of three classes, *viz.*, A, B and C. They are given instructions by technical staff and issued the improved seed for further multiplication. They grow the crop as per instructions. The staff of certifying agency inspects the crop from time to time up to harvesting and threshing. After threshing the seed is purchased by Government at already fixed price and handed over to the disributing agency. Thus the registered seed is used for general distribution to the farmers in the block.

(5) *Certified seed :* It is the name given to any seed that has been certified by the certifying agency as a good seed for sale and distribution to farmers. This is not necessarily the progeny of improved seed but is good in physical qualities to meet the farmers' requirement. It has been observed that the seed distributed to farmers in blocks is generally called as 'certified seed'. This seed is actually the progeny of registered seed. This is due to the fact that the amount of registered seed is not considered sufficient to meet the desired demand of farmers, and, therefore, it is further multiplied in block area by some farmers, certified and then distributed to every farmer.

Certified seed can be produced by any farmer but must be approved and certified by the seed certifying agency and seed testing authority for distribution as a certified seed.

Sequence of seed multiplication : The time taken in seed multiplication should not exceed five years in any case, i. e., the seeds of an improved variety must reach every farmer within a period of five years of its release The sequence of seed multiplication stages within the five years' period has been shown diagrammatically in Fig 54 with arrows as indicators to the next stage :

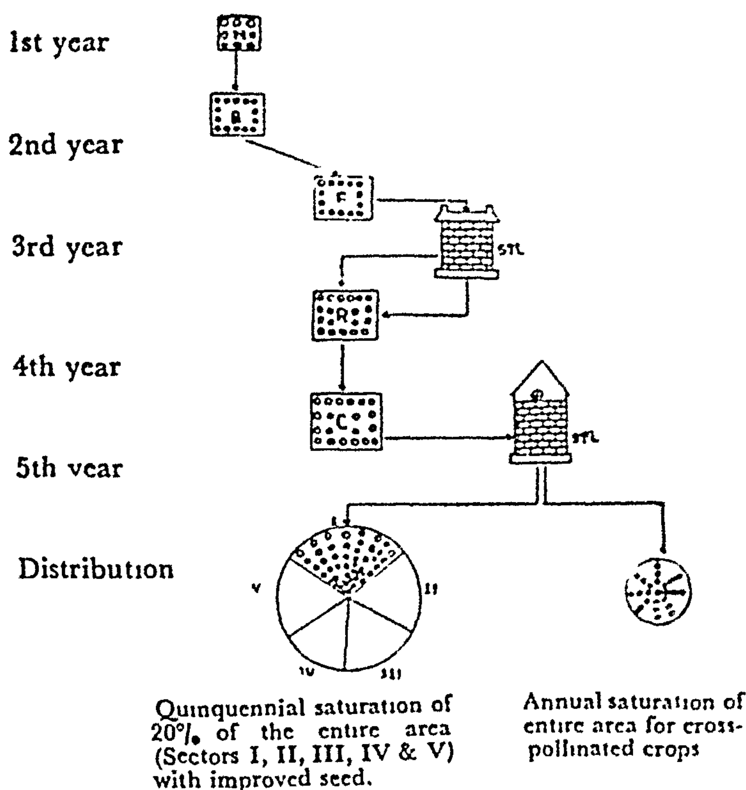


Fig 54
Sequence of seed multiplication (*After Chalam and Neelakantan*, 1962)

In our country the seed multiplication, certification and distribution is mainly carried out by the National Seeds Corporation established by the Government of India in July 1963. This Corporation is also imparting training to the workers in seed testing, certification and multiplication. N. S. C. has been steadily extending its area of work in collaboration with the State Departments of Agriculture.

DISTRIBUTION

The distribution of improved seeds to the farmers is carried out by Blocks and Co-operatives in India. These agencies receive the improved seed in bags or containers with properly affixed labels indicating the standard of class of seed. This label bears the information (Table 21) regarding the seed and serves as an evidence of genetic identity and varietal purity of the seed in the

bag or container. The labels used are of different colours for different classes of seeds.

Table 21. Information regarding seed contained in affixed label

Kind......

Variety... ... .

Class . . . .. .*Foundation/Registered/Certified

Source ....*Govt. Seed Farm/Certified grower

Address........

Germination percentage ......

Purity percentage.. .. ....

Moisture content ... .

Quantity offered for certification . ..

Seal or Insignia of certifying agency

*Please strike out whichever is not applicable.

(*After Chalam and Neelakantan*, 1962).

In case of self-pollinated crops, when once the seed has been distributed to the farmers there is no need to distribute it again in next year freshly but the farmers are advised to save the seed from the crop grown and use it again in coming year for raising the new crop. This process is repeated every year by farmers to meet their requirement of seed for sowing. After 7 or 8 years the seed may be renewed by the distributing agency. This is done with the idea that after 8 years or so due to admixtures and some amount of cross-pollination, the seeds may deteriorate in their quality and the purity may be lost.

In case of cross-pollinated crops, when the improved seed is of hybrid origin, the farmers are supplied fresh seeds every year to raise the new crop This is done for the reason that the hybrid vigour is lost and spoiled in F_1 due to segregation and free cross-pollination and, therefore, the use of F_2 seeds has no advantage over local variety. If the variety is mass selected or composite no need to redistribute the new seeds every year but farmers may be advised to keep some plot isolated and use mass selection in it for collecting the seeds for next year's crop.

PROCUREMENT OF IMPROVED SEED

A farmer can approach one or more of the following agencies for obtaining the pure seed of improved varieties at the time of sowing :

(1) Government or Co-operative Seed Stores.

(2) Registered seed-growers.

(3) National Seeds Corporation, New Delhi or its agents in locality.

(4) Agricultural Universities.

For information and advice on particular points the farmer may contact the Block Development Office which may help or guide in all spheres of agriculture.

MAINTENANCE

The improved varieties, if not maintained, are lost and thus the whole labour wasted in their production goes in vain. It is, therefore, essential to maintain the improved varieties year after year so that their seeds may be supplied every year to the farmers.

The work of maintenance is carried out by technical staff at various research stations The original plant breeder also maintains the varieties with their parents.

Self-pollinated crops : In self-pollinated crop the variety, may be a selection or hybrid, is maintained by practising the pure-line selection with all precautions of distance and admixture every year in the variety and its parents.

Cross-pollinated crops : For maintaining the hybrid varieties of cross-pollinated crops, the following five steps are practised every year :

(1) Maintenance of the parental inbreds.

(2) Production of parental inbreds.

(3) Production of single crosses.

(4) Production of double crosses.

(5) Distribution of double cross seeds to farmers.

If even one step is not carried out in any one year the continuous supply of hybrid seed is cut off and if the first step is not followed even the hybrid variety is lost.

If the variety is mass selected, it is maintained by growing in isolated area and practising the mass selection in it every year.

A comparative description of seed multiplication, distribution and maintenance in different types of crops has been given in Table 22.

SEED TESTING

The seed testing was started as early as 1816 when Switzerland passed a law which required clove seeds to be inspected before being offered for sale. In Germany the seed testing was started in the year 1869, i.e., same decade in which Mendel published his experiments on pea and laid the foundation of genetics. Nobbe, then Agriculture Adviser to Germany, conducted detail studies on seed testing and published the findings in his book entitled "The Handbook of Seed Science" which was the first book on seed in the world. Subsequently, seed testing developed in Europe and other countries. In the beginning, major aim of seed testing was to identify weed seeds which create hazards when present in crop seeds. Since 1889 the seed testing also came to include analysis for purity and germination. In 1921, the International Seed Testing Association (I. S T. A.) was established. The initial purpose of this union as well as the Association of Official Seed Analysts of U.S.A. was to promote uniformity in seed testing methods.

In India the seed testing work was started in the Second Five Year Plan with sanction of a grant for establishment of four seed testing laboratories at I. A. R. I., New Delhi, Hyderabad in A.P., Ludhiana in Punjab and Patna in Bihar. The Central Seed Testing Laboratory at I. A. R. I., New Delhi came into existence in November, 1955. In the beginning these laboratories were meant for vegetable seed testing attached to the Horticultural Section of the State Agricultural Departments. Subsequently with the development of seed producers, seed dealers and Government seed multiplication farms for important agricultural crops, one seed

Table 22 Comparison of seed multiplication, distribution and maintenance between self-pollinated and cross-pollinated crops

S No.	*Comparison between*	*Self-pollinated crops*	*Cross-pollinated crops*
1.	**Isolation distance**	150 cms.	Minimum safe distance is kept 150 metres.
2	**Multiplication**	Further multiplication is carried out from the seed supplied. It is not essential that every type of seed is directly obtained from nucleus seed every year	Every year four steps are carried out : maintenance of parents, and production of inbreds, single crosses and double crosses.
3.	**Workers needed in multiplication**	Even ordinary farmers, if issued some instructions, can carry out the work of multiplication.	Only the research workers or technically trained farmers can carry out the work of seed multiplication.
4.	**Distribution**	Improved seeds are distributed only once in many years. No need to distribute fresh seeds every year.	Fresh hybrid seeds are issued every year to the farmers.
5.	**Maintenance**	Very easy to maintain the once produced variety.	Very laborious task to maintain the once produced variety.

testing laboratory was established in each. State (See Appendix I for addresses).

Definition and objective: Seed testing means the analysis of seed sample to determine its quality. Thus the main objective of seed testing is to judge the quality of seed, i.e., varietal purity, moisture content, viability percentage, occurrence of weed seeds, presence of seed-borne diseases, etc., to know whether it is physically fit or not for the following purposes:

(1) Raising new crops
(2) Selling in the market
(3) Certification

Seed testing agencies: The work of seed testing in India is done by two agencies, *viz.*, the Seed Testing Laboratories and the National Seeds Corporation.

The functions of the Seed Testing Laboratories are:

(1) To carry on fundamental research on seed testing methods.
(2) To fix up the minimum seed standards for purity, germination and moisture content for different crops.
(3) To impart training to the workers on seed testing and certification.
(4) Seed certification.
(5) To make recommendations for formulating the seed laws.
(6) To play a statutory role in implementing the provisions of seed law, i.e, the seed analysis conducted in a Seed Testing Laboratory will be valid in a court of law.
(7) To set up a museum of vegetable and weed seeds.

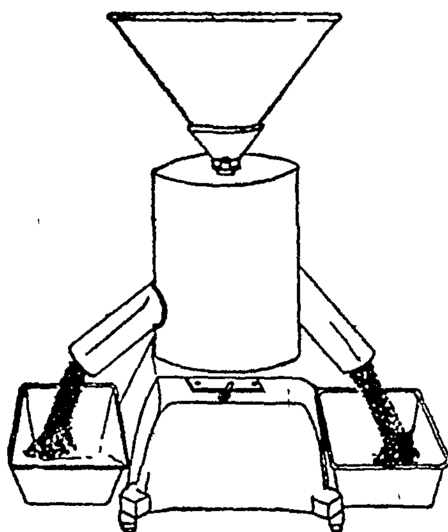
The functions of the National Seeds Corporation are:

(1) Seed multiplication and distribution.
(2) Seed testing and certification.
(3) To make recommendations for fixing up standards and formulating seed laws.

Type of tests: Under seed testing the following different tests are carried out to determine the quality of seed:

(1) Purity,
(2) Germination,
(3) Moisture content, and
(4) Seed-borne diseases.

Before going into their details, it must be learnt that the methods used in testing the seeds are more or less uniform and practically the same in all the countries of the world. This is due to the efforts of International Seed Testing Association which has been trying for the last so many years to bring the uniformity in methods of seed testing in the different countries of the world. Same procedures and similar instruments are being used in each country by its seed testing laboratory and the staff is also being trained practically in the same way Due to this uniformity in the seed testing methods, the results obtained from a given seed sample at one seed testing laboratory can be reproduced at any other station in any part of the world where, on testing, it will give the same results. In this way it is possible to import and export the improved seed and to issue an International Seed Analysis Certificate. Indeed such a uniformity in seed testing is essential all over the world for convenience of international seed trade.



F55ıg

A Gamet seed mixture and divider, which is used to reduce a laboratory bulk seed sample to a working seed sample It makes the use of centrifugal force to mix and scatter the seeds over the dividing surface (*After 'Seeds' —the Yearbook of Agriculture, U. S D A., U S. A*, 1961)

Sampling: It is taking of samples from the different sources such as bags, heaps and drums for the purpose of making different tests as given previously. The sample is taken in different ways from the different sources.

From heaps: If the seed is in a heap, the samples from seven places at equal distances are taken by hand pushing. All the samples thus

drawn are merged together into one and the work of sampling is complete.

From bags : If the total seed is in five or less than five bags, one sample is taken from each bag by inserting the trier. If the seed is in more than five bags, one sample is taken from every fifth bag with the help of trier. All the samples are mixed together into one.

From drums : If the seed is in drums, the samples are taken from the drum. The only difference is that hand is used in taking up the sample instead of using the trier.

Preparation of sample for testing : The sample collected in the aforementioned way is known as **mechanical sample.** It is properly mixed by hands or mixing machines so that every portion of it becomes homogeneous in composition. This sample is very large and, therefore, it is divided into 4 or 5, or even more groups, each known as **working sample or analytic sample.** Dividing may be done either by hands or by divider such as Boerner divider or Gamet precision divider specially meant for this purpose (Fig. 55) These mechanical mixers and dividers are faster and more accurate than old hand methods.

All the tests are made in analytic or working sample.

Purity test : The purity test is done to estimate the undesirable constituents inside sample. It is done in duplicate, i e., two analytic samples are tested separately and their results are averaged for getting the correct data on the purity percentage.

Following equipment is used in purity analysis of seed to help the analyst in doing efficient and accurate work :

(*1*) *Purity workboard* : It provides a clean and comfortable work area for the purity analysis.

(*2*) *Forceps* : They are used for separating the different components of seed under analysis.

(*3*) *Magnifiers* : They are needed in analysing seeds of small sizes and in identifving weed seeds.

(*4*) *Sieves* : They are useful in a rough preliminary separation of pure seed from other extraneous material.

(*5*) *South dakota seed blower* : It is used in blowing light chaffy material.

(6) *Balance :* It is needed for weighing different fractions of seed and seed samples. Many types of balances such as Cent-o-gram, Torsion, Chain-o-matic etc. are available in market. For details it is advisable to see Seed Testing Manual.

(7) *Dishes :* Small round aluminium dishes are very useful in moving and taking the seed, inert matter, weed seeds and other seeds from bag to working table and from working table to balances for weighing.

(8) *Smaller sample pan* for keeping the seed sample.

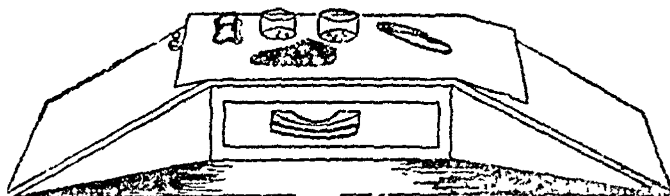


Fig. 56

A seed sample working table which elevates the working area above the level of the table top and so minimises tireness of eyes, neck and shoulders of the technician who makes an analysis for the purity of seed (*After 'Seed' —Yearbook of Agriculture, U S D A , U S A* , 1961)

The analytic sample is weighed and then spread on a glass plate or on a smooth table (Fig. 56) It is examined particle by particle by eyes usually with the help of magnifying glass or lens. Sometimes special methods, e g , ultraviolet light and others are also used for this purpose. The working sample is separated into two parts, *viz.*, pure seed and impurities The pile of impurities is further examined and separated into the following components :

1 Inert matter, e.g , sand, straw, stones chaff, ergot and sclerotia.

2. Other seeds, e g., weed seeds and other crop seeds

3. Defective seeds, e g , diseased, broken, shrunken and insect possessing seeds.

Any broken seed, larger than half of the original seed in size, is included into the pure seed.

After making all separations, each component is weighed separately and then the purity percentage is calculated on the basis of weight.

Suppose two analytic samples 'A' and 'B' were taken from wheat bags and on analysis the following observations were made:

Sample A

1. Weight of the sample =25 gms.
2. Weight of the inert matter =0.75 gms.
3. Weight of other seeds =0.50 gms.
4. Weight of defective seeds =0.25 gms.

Total amount of impurities $=0.75+.50+0.25$
$=1.5$ gms.

Percentage of impurities $=\frac{1.50\times 100}{25}$

$=6\%$

Purity percentage $=100-6=94\%$

Sample B

1. Weight of the sample =25 gms.
2. Weight of the inert matter =1 gm.
3. Weight of other seeds =0.25 gms.
4. Weight of defective seeds =0.50 gms.

Total amount of impurities $=1+0.25+0.50$ gms.
$=1.75$ gms.

Percentage of impurities $=\frac{1.75\times 100}{25}$

$=7\%$

Purity percentage $=100-7=93\%$

If the difference in purity percentage of these samples, which are from same source, is high, fresh samples are to be taken and the test is repeated

Average of both samples is $(93+94)\div 2=93.5$. Thus 93.5 is the purity percentage of the mechanical sample taken from wheat bags.

Impurity percentage is also known as **dockage.**

Germination test : The purpose of germination test is to determine the percentage of viable seeds so that the germination percentage may be known. Several methods have been developed to test the germination percentage but only two, which are used in routine investigations, have been described here.

The ideal method for germination test would be to sow the seeds in the field and count the seedlings but this is usually not practical for two reasons. Firstly, the results of germination analysis are required before sowing time and, secondly, the field conditions are not standard one but variable from place to place. The results taken under such conditions are not reproducible and they must, therefore, be carried out under controlled and standardized conditions in laboratories as far as possible.

The following equipment is generally utilized in conducting the germination test :

(1) *Germinators :* Germination cabinets or temperature controlled rooms are the usual methods for controlling the humidity and temperature. They are least needed in a place like Bangalore where ideal temperature is prevailing throughout the year.

(2) *Refrigerator :* It is used for prechilling the seed samples to break dormancy wherever necessary. This special cooling apparatus is not required in Srinagar or Himachal Pradesh where cooler conditions are naturally existing to meet the needs.

(3) *Germination boxes :* Wooden benches and boxes filled in with sand are the best things for germinating seeds. The sand to be used should be either fresh or sterilized if it has been used repeatedly. It is always good to use fresh sand if easily available to avoid the need for sterilization. The sand can be sterilized by either putting the boxes in oven or connecting them with steam pipe.

(4) *Petridishes and paper towels :* They are cheaper and easily available for germinating seeds on small scale.

(5) *Blotter and cotton :* They are put inside the petridishes and paper towels to conserve and maintain the moisture so that seed may get it continuously during germination.

(6) *Dissecting equipment :* Scalpels or knives are used to cut the seeds into two equal halves for treating with tetrazolium.

(7) *Tetrazolium chloride & Bromide* are chemicals used to stain the bisected seeds. On the basis of staining taken by seed parts the viability of seeds is judged and inferences on seed germination are drawn.

(8) *Counting board, Impression board, Sand and water mixer, wash bottles, trays, etc.*, are also needed to speed up the work of germination test.

(1) *Germination experiment method :* In this the four groups of seeds, each of 100 seeds, are taken from four analytic samples of the same source. Seeds of each group are germinated separately and the germinating seeds are counted. Thus, the germination percentage is calculated for each group and then the average of all the four is taken. This is the germination percentage of the source from which the original sample was taken.

If there is more than 10% difference of germination in any two groups, the fresh samples are taken and the experiment is repeated.

The seeds are grown in proper medium under optimum conditions which vary with the species to be tested. Seeds of cereals germinate equally well both in sands and filter papers, and those of legumes better in sand. Soil is also sometimes used as germination medium. Filter papers are always put in petridishes and the sand and soil are put either in wooden boxes or plates. For germination, optimum conditions of temperature and humidity are provided throughout the testing. Most of the seeds germinate at temperatures between 18° to 22°C and the relative humidity between 70 to 90%. But for certain seeds, specially grasses, the alternating temperatures between 20° to 30°C, or between 10° to 30°C are needed. Most seeds germinate easily in the diffused light or in the dark but some seeds, in addition, require special treatment of light, darkness, cold, etc. Fresh air is also needed to remove CO_2 and to supply O_2 for respiration.

The humidity is maintained by supplying water to the medium from time to time. Temperature is maintained by keeping the dishes or boxes in cold places of freeze and in hot places or

oven as is convenient Darkness and light may be provided by keeping the boxes or dishes into dark rooms and sunlight respectively. Provision for fresh air and supply of oxygen is made either by keeping the experiment in open air or by keeping the holes on sides of wooden boxes which may serve the purpose of ventilation without creating drought around the seeds

The duration of germination test varies from 7 to 28 days depending upon the species under test. Seven days are for those species which germinate very quickly and evenly and 28 days are for those which germinate very slowly. The germinated seeds are counted after definite number of days as the first count is made after 3 or 4 days in case of cereals and clovers, and after 7 days in case of grasses. Each subsequent counting is made after a fixed interval throughout the test.

The seeds are considered to have germinated when they have produced a healthy root with root hairs and plumule. At each count, the number of germinated seeds is noted and then they are removed. If necessary, the remaining seeds may be transferred to a fresh seed bed or medium. At the end, total number of germinated seeds are obtained. The figures of all the four groups are added up together and average percentage is calculated This gives the germination percentage in seeds.

Suppose four groups of wheat seeds, i e , A, B, C and D, each having 100 seeds gave the following number of germinated seeds (Table 23).

Table 23 Number of germinated seeds obtained in four groups of seeds separately at each count

Count No.	*Group A 100 seeds*	*Group B 100 seeds*	*Group C 100 seeds*	*Group D 100 seeds*
1	10	12	11	13
2	20	25	19	23
3	25	25	30	25
4	20	15	14	15
5	10	6	10	8
6	3	4	9	5
7	2	5	1	3
Total	90	92	94	92

Here the difference between any two groups is not more than 4 and, therefore, no need to repeat the experiment.

$$\text{Germination percentage} = \frac{(90+92+94+92)\ 100}{400}$$

$$=92$$

Germination experiment method gives the accurate information about the germination percentage but takes too much time.

(2) *Tetrazolium method:* In this method a chemical called 2, 3, 5-triphenyl tetrazolium chloride discovered by Lakon in Germany is used to judge the viability of seeds. The concept behind this method is that the viable seeds are supposed to germinate and if their number can be counted, the germination percentage can be calculated without conducting the germination experiments.

Hundred seeds are taken at random from an analytic sample and soaked in tap-water overnight. The seeds are then bisected longitudinally. One half of each seed is retained and the remaining hundred halves, each containing some portion of embryo, are placed in dish and just covered with 1% aqueous solution of tetrazolium chloride which is almost colourless. They are left as such in dishes at 20°C for four hours. The seeds are then washed in tap-water and examined. Some halved seeds will be found red stained and some will not. This is due to the reduction of tetrazolium chloride by living cells which in its reduced state becomes red in colour. Thus it is quite possible to distinguish the viable bisected seeds from the nonviable on the basis of distribution of red colour. The viable ones are counted which directly give the germination percentage of seed sample.

This test gives a fairly accurate idea of germination percentage and can be completed within 24 to 48 hours. Hence, it has the advantage of being completed in much shorter period but involves more laborious hand work than that is needed in germination experiments. In this case, close scrutiny of each seed is required which may be very difficult in small seeds and, therefore it is not applicable in such cases where seeds are very very minute in size.

Real value of seed : The real value of seed, which is also known as utility percentage, conveys the value of a sample in comparison to another sample and can be defined as follows.

The real value of the seed is the percentage of pure germinating seeds

It is calculated by the following formula ·

$$\text{Real value of the seed} = \frac{\text{Purity\%} \times \text{Germination\%}}{100}$$

Suppose there are two samples, 'A' and 'B', of wheat exactly of same kind with no serious impurities. The farmer or the merchant wants to know which is the better sample ? The figures for purity percentage are 90 and 95, and for germination percentages are 90 and 85 respectively for both the samples Now, it is very difficult for them to distinguish the better sample at a glance from the study of figures of purity and germination percentages In order to facilitate this comparison, the real values of seeds are calculated in both cases :

$$\text{Real value of 'A'} = \frac{90 \times 90}{100} = 81\%$$

$$\text{Real value of 'B'} = \frac{95 \times 85}{100} = 80{\cdot}75\%$$

By comparing these two figures of both samples it is clear that sample 'A' is slightly superior to sample 'B'.

Sometimes the real value may not convey the correct information ; for instance a seed sample having higher real value but more impurities specially undesirable weed seeds, will be of infeiror quality. Real value says that sample 'A' is superior while in reality the sample B may be superior to A.

(3) *X-ray method* : This was developed by Drs. Simak and Gustafsson in Sweden and is based on the principle that different parts of a seed such as seed coat, endosperm and embryo absorb X-rays to different extent which can be differentiated in X-ray pictures Thus it is possible to draw inferences on relative development of embryo and endosperm for comparison with germination. The small dose of X-ray does not affect the viability of seeds.

Moisture content : Besides the purity and germination percentages, the moisture content is the another important conside-

ration in testing the seeds. The knowledge of moisture content helps the farmers and merchants in storing their seeds for some time before sowing and selling. A high moisture content may result in rapid deterioration of seed. For example, the wheat seeds with a moisture content of 15% can be stored safely but if the moisture content is more than 17% the sample will deteriorate much more rapidly. If it is 20% or above the seed mav become totally useless and valueless for sowing in a relatively short period.

The moisture content of a seed sample can be determined simultaneously with purity test or sometimes after the purity analysis. There are three methods commonly used for determining the moisture content of the seeds, namely, oven method, electrical method and oil distillation method. Among all the three the first, i.e., oven method is commonly used for routine investigations.

(*1*) *Oven method*.. Usually three portions, each weighing 5 gms. are taken from an analytic sample and weighed out. They are dried at 130°C for 90 minutes in an oven. Again they are weighed after drying and the difference in weight before and after heating. will be the amount of moisture contained in seed. The moisture percentage is calculated from this difference on the basis of weight as follows :

$$(M_2-M_3)\ \frac{100}{M_2-M_1}$$

where, M_1 is weight of dish with cover. M_2 is the weight of dish with cover and seed before drying and M_3 is the weight of dish with cover and seed after drying. All weights are taken in grams to an accuracy of 1 mg.

The results of triplicate determinations must not differ by more than 0 2%. Should the difference be greater than this, the test must be repeated in duplicate or triplicate.

A temperature of 130°C is excessive for tree seeds and some other seeds such as *Allium* spp., *Capsicum* spp., *Raphanus*, etc. which contain volatile oils. In such seeds the temperature is kept at 105°C for 16 hours instead of 130°C for 90 minutes. Both systems are similar except difference in temperature and drying period

Table 24. Standards of purity and germinability for foundation seed of vegetable and field crops (*After Amir Singh*, 1968)

Sl No	Crop		Standard suggested (per centage)	
	Common English name	Botanical name	Purity	Germinability
		A. Vegetables :		
1.	Asparagus	*Asparagus officinalis*	98	75
2.	Bean (French bean)	*Phaseolus vulgaris*	98	75
3.	Beet	*Beta vulgaris*	98	70
4	Bhindi (Okra)	*Abelmoschus esculentus*	99	60
5.	Bottle Gourd	*Lagenaria siceraria*	99	60
6	Brinjal (Egg plant)	*Solanum melongena*	98	70
7.	Cabbage	*Brassica oleracea* var. *capitata*	98	65
8	Capsicum (Chilli)	*Capsicum annuum*	98	60
9.	Carrot	*Daucus carota*	95	60
10.	Cauliflower	*Brassica oleracea* var. *botrytis*	99	75
11.	Celery	*Apium graveolens*	99	75
12.	Vegetable Cowpea (Lobia)	*Vigna sinensis*	98	75
13.	Cucumber	*Cucumis sativus*	99	75
14.	Knol khol	*Brassica caulorapa* var. *capitata*	99	75
15.	Leek	*Allium porrum*	98	60
16	Lettuce	*Lactuca sativa*	98	60

1	2	3	4	5
17.	Luffa Gourd	*Luffa acutangula*	98	60
18.	Methi	*Trigonella foenum-graecum*	98	75
19.	Onion	*Allium cepa*	98	70
20.	Parsley	*Petroselinum hortense*	98	65
21.	Peas	*Pisum sativum*	98	75
22	Radish	*Raphanus sativus*	98	75
23.	Spinach (Palak)	*Spinacia oleracea*	98	60
24.	Sem (Lab-lab)	*Dolichos lablab*	98	75
25.	Squash	*Cucurbita moschata*	98	70
26.	Tomato	*Lycopersicon esculentum*	98	75
27	Turnip	*Brassica rapa*	98	75
28.	Water Melon	*Citrullus vulgaris*	99	70
		B. Field Crops :		
1.	Wheat	*Triticum aestivum*	98	90
2.	Barley	*Hordeum vulgare*	98	90
3.	Paddy	*Oryza sativa*	98	85
4.	Cotton	*Gossypium* spp	98	80

This method, although not very accurate for research work, gives fairly reliable information for routine investigations.

(2) *Electrical method :* In this the electric moisture testers are used. They measure the electrical resistance through seeds which varies according to moisture content. In India only two types of testers, Steinlite and Universal, are used by the National Seeds Corporation and other organisations concerned with seed testing.

These moisture testers are expensive, require calibration and if misused or handled by untrained workers, they are subject to error.

The advantage of this method is that the moisture testers are easily portable and the test can be made within two minutes' time.

(3) *Oil distillation method* · This method, though time-consuming, is much less expensive and accurate enough for determining the moisture content of seeds. The inexpensive aspect of this method requires a 500 grams scale spring balance, 200°C (392°F) thermometer, a one litre container, and a source of heat such as kerosene burner. The container with 200 gms of vegetable oil and 100 gms. of seed is heated to 90°C for 15 minutes. At this point water is evaporated but the oil is not boiled. The difference in weight of container and contents before and after heating indicates the moisture percentage in the seed.

Disease free : There are certain diseases, as grain smut of *jowar*, cereal smut of millets and bunt of wheat, which spread through seeds. Their causal organisms remain associated with the seeds and usually can not be observed with naked eyes. The seeds, therefore, must be rejected from mixing with other seeds as well as entry into the market trade.

Seed certification : The term 'seed certification' means a system of approving a crop variety seeds by seed certifying agency as an improved seed. The purpose of seed certification is to make available to farmers the good quality seeds and other propagating material. This work is carried out by Laboratories, National Seeds Corporation, etc., who send their inspectors for certification of seeds. Inspectors inspect the crop from sowing to the threshing stage with all precautions. The decision, whether

Table 25. Field Inspection Report (*After Amir Singh*, 1966)

.... Name of Grower	.... Address	.... Farm Located
.... Field No.	.... Class being Inspected	.... Acres in this Field
.... Variety	.... Source of Seed	.... Total Area

Per cent Mix.................... Kind .... Per cent Loose Smut......

Preceding crop........................ Other Diseases ....

Isolation............................ ... .

Plants of other crops per acre :

1.........................

2.........................

3.........................

4.........................

5. .. ..

	Definite Mixture	Distinguishable Varieties	Disease Present
1			
2			
3			
4			
5			
Mean			

Remarks . . . .

Weeds present ·

1 . . . .

2 . . . .

3 . . . .

4 . . . .

5 . . . .

Estimated Yield . . . .

Does this field have proper variety characteristics ? . . . .

Does this field meet field standard for certification ? . . . .

Dated : . . . .

Inspected by . . . .

the crop is to be certified or not, is made on the basis of the reports obtained from the inspectors concerned.

Seed laws or seed control laws: They are those laws which fix up the minimum limits of every test known as permissible limits and control the seed trade. They are applicable to every type of seed coming into the market, may be from within the country or outside the country. Already in India, the Seed Bill has been approved on November 18, 1965 to regulate the quality of seed in trade and agricultural transactions.

Questions

1. Define the improved seed and state factors determining it.
2. Who does produce the improved crop varieties and where ?
3. Mention the names of different methods employed for evolving the improved crop varieties.
4. How a variety is named and released ? Describe in brief.
5. What is the importance of seed multiplication in plant breeding and give its different stages ?
6. List the names of different agencies and personnel concerned with seed multiplication programme.
7. Compare the distribution of improved seed of self-pollinated crops with that of cross-pollinated crops.
8. What are different steps involved in the maintenance of hybrid varieties in maize ?
9. Why the seeds of hybrid maize are distributed freshly to the farmers every year ? Account for it with reasons.
10. Discuss the aims and objectives of seed testing in agriculture.
11. What are the various seed testing organisations in India and describe their functions separately ?
12. What different types of tests are conducted in a seed sample to determine its quality ?
13 Define the term 'purity' and describe the procedure of its determination in a seed sample.
14. Calculate the percentage purity of the wheat sample with the help of data given as follows :

Weight of the sample	=30 gms.
Weight of the inert matter	=0.75 gm.
Weight of other seeds	=1.0 gm.
Weight of defective seeds	=2.25 gms

15. List the names of different methods commonly used to determine the germination percentage of a seed sample. Describe the tetrazolium method in detail.
16. Two cartloads of wheat grains came into the market of Udaipur and a merchant wanted to purchase only one. What criteria will be adopted to sort out the cart containing superior quality of wheat grains? Under such circumstances which test is needed so that the better one can be distinguished quickly?
17. Following data have been provided to you for two samples 'A' and 'B' of maize:

A. Germination percentage	=90%
Purity percentage	=95%
B. Germination percentage	=88%
Dockage	= 4%

Determine which sample is superior?

18. Describe the most common method of estimating the moisture content of seeds
19. Differentiate between the followings:
Foundation seed and registered seed.
Mechanical seed sample and working seed sample.
20. Give the various functions of the following organisations: Seed Testing Laboratory, the Central Varieties Release Committee, National Seeds Corporation and Registered seed growers.
21. Comment on the followings:
Dockage, Lakon, Seed Bill, Seed certification, Maximum permissible limits and Nucleus seed.

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Glossary

GLOSSARY OF PLANT BREEDING TERMS

Abbreviations used in glossary are clarified here *adj*=adjective, *e.g* =for example, *et al.*=and others, *Gk.*=Greek, *i.e* =that is, L.=Latin, n.=haploid number of chromosomes, 2n=diploid number of chromosomes, *n*=noun, *Opp.*=Opposite, *pl.*=plural, Sp =Spanish, *v*=verb, *x*=haploid generation, 2*x*=diploid generation, *etc*

Å. Angstrom, 0.0000001 mm

Acclimatization *n.* (L. *ac* or *ad*=to+*clima*=region). The adaptation of an individual, plant or animal, or a population to a changed climate for a number of generations, *Synonym*, **acclimation.**

Albino *n* (Sp. *albino*=white, L *albus*=white). A plant lacking chlorophyll or an animal lacking normal pigmentation. Albinic condition is determined by recessive genes (cc in animals and ww in plants).

Allogamy *n* (Gk *allos*=other+*gamos*=marriage). Cross-pollination. *Opp.*, **autogamy.**

Amphimixis *n.* (Gk *amphi*=both+*mixis*=mixing) It is the normal sexual reproduction in which the morphologically dissimilar male and female gametes unite together for the formation of zygote The meiosis and fertilization are the essential features of it *Opp* , **apomixis**

Analytic seed sample. The seed sample obtained by dividing the mechanical seed sample in which the analysis for different tests is carried out conveniently.

Androgenesis *n.* (Gk *aner*=male+*genesis*=descent). Male parthenogenesis.

Angstrom *n.* (A. J. Angstrom, Swedish physicist). One tenth millionth part of a millimetre. Symbol **Å.**

Anthesis *n* (Gk *anthos*=flower). The stage or period of opening of a flower and its pollination.

Antipodal cells *n.* (Gk. *anti*=against+*pous*=foot). A group of three cells at the chalazal end of embryosac, i e , at the opposite end of the egg-cell

Apogamy *n.* (Gk. *apo*=away+*gamos*=marriage). A type of apomixis in which the embryo develops from the cells other than egg-cell, i.e., synergids or antipodal cells without fertilization and with or without meiosis. It is of two types :

(i) **Haploid apogamy.** Meiosis takes place in synergids or antipodal cells and thus they are haploid giving rise to the haploid apogamy. *Synònyms,* **meiotic apogamy** and **generative apogamy.**

(ii) **Diploid apogamy.** Meiosis is absent and synergids or antipodal cells remain diploid giving rise to the diploid apogamy. *Synonyms,* **somatic apogamy** or **euapogamy.**

Apomixis *n.* (Gk. *apo*=away+*mixis*=mixing). An abnormal sexual reproduction in which the embryo develops from the egg-cell or cell associated with it without fertilization and with or without meiosis. It is of various types such as parthenogenesis, apogamy and apospory. *Opp.,* **amphimixis.**

Apospory *n.* (Gk. *apo*=away+*sporos*=seed). A type of apomixis in which the embryo develops from the integuments or nucellus.

Artificial selection *n* See **selection.**

Artificial vegetative reproduction. See **vegetative reproduction.**

Asexual reproduction *n.* (Gk. *a*=without+L. *sexus*=sex). A type of reproduction which takes place with the help of one sex instead of fusion of gametes from two sexes.

Autogamy *n* (Gk *autos*=self+*gamos*=marriage). Self-pollination. *Opp* , **allogamy.**

B_1, B_2, B_3. First, second and third backcross generations respectively. The first backcross is made by crossing hybrid with one of its parents, the B_2 is made by crossing the B_1 plants with the same parent, and so on in B_3 and subsequent backcross generations. *Synonyms,* **BC_1, BC_2, BC_3.**

Backcross *n.* In plant breeding, a cross of a hybrid, i.e., F_1 with one of its parents and the purpose is to transfer a specific gene from an undesirable variety to another commercially desirable one lacking in that particular character. In

genetics, a cross of hybrid with a homozygous recessive parent and the purpose is to test the gametic ratio of F_1.

Backcross breeding. A type of breeding method in which the backcrossing is carried out for several generations followed by subsequent selection until a desired combination of characters from the recurrent parent and one or two desired traits from the non-recurrent parent is obtained in the progeny. *Synonym*, **backcross method of breeding.** In livestock it is called line breeding

Balanced heterosis See **heterosis.**

Biometrics *n.* (Gk. *bios*=life+*metron*=measure). Statistics applicable to biological data.

BC_1, BC_2, etc See B_1, B_2, etc.

Botany *n.* (Gk. *botane*=pasture). A branch of biology which deals with the study of plants Its branches are : **Pure Botany** such as morphology, physiology, taxonomy, ecology, etc., and **Applied** or **Economic Botany** such as plant breeding, plant pathology, agronomy, horticulture, forestry, etc. *Synonym*, **phytology**

Breeder's stock seed. The improved seed increased from the nucleus seed under the guidance of original plant breeder It is genetically and phenotypically cent per cent pure and used as a source for foundation seed *Synonym*, **Breeder's seed.**

Breeding. The improvement of plants or animals by selection, hybridization, etc.

Bud mutation. The mutation in the bud which causes variation in it and gives rise to a branch, flower or fruit unlike rest of the plant. *Synonyms*, **bud sport** and **bud variation**

Bud selection. A form of clonal selection in which the bud is made the unit of selection.

Bud sport See **bud mutation.**

Bulk method. A hybridization method used in self-pollinated crops in which the segregating generations of hybrids are grown in bulk plot, with or without mass selection, and with single plant selection in F_6 and later generations. *Synonyms*, **bulk breeding** and **bulk method of breeding.**

Bulk seed sample. The entire quantity of sample received in a seed laboratory for testing.

Certified seed sample. The samples which are submitted by a seed certification officer or inspector for determining the quality to be tagged and sold as certified seed.

Certified seed. The progeny of foundation, registered or any other seed which has been certified by a certifying agency and possesses a satisfactory level of genetic identity and purity.

Chalazogamy *n.* (Gk. *chalaza*=small tubercle+*gamos*=marriage). The fertilization in which the pollen tube enters the embryo-sac through the way of chalaza.

Cleistogamy *n.* (Gk. *kleisto*=closed+*gamos*=marriage). Self-fertilization within the closed flowers.

Clone *n.* (Gk. *klon*=twig, Webber). A group of plants obtained vegetatively from a single plant.

Clonal selection. A method of selection of desirable clones from the mixed population of a vegetatively propagated crop.

Combining ability. The relative ability of an inbred line or a clone, when crossed to another inbred line or clone, to transmit desirable traits or a specific trait to its cross. It is of two types :

(i) **General combining ability** "is the average performance of a line in hybrid combination", and

(ii) **Specific combining ability** is used to indicate "those crosses in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved".

Compartmental selection. A form of mass selection in which the whole field is divided into different compartments so as to eliminate the effects caused in plants by variability in soil fertility.

Composite seed sample. A seed sample composed of mixture of different sub-sample taken from various parts of a seed lot.

Conjugation *n.* (L. *conjugatus*=to join together). The fusion of isogametes (morphologically similar gametes) as in lower plants like algae and fungi.

Conventional breeding methods. The classical methods of crop improvement such as different types of selections, hybridizations, and plant introduction and acclimatization.

Cross *n.* Used to indicate mating of two or more parents of unlike genetical constitutions. Also used for a hybrid.

Single cross. A cross between two inbreds, A×B.

Three way cross. A cross between a single cross used as female and an inbred used as male, i.e., (A×B)×C

Double cross. A cross between two single crosses involving four different inbreds, e.g., (A×B)×(C×D).

Top cross. A cross between an open-pollinated variety and an inbred. *Synonym*, **inbred-variety cross.**

Synthetic cross. A cross among many inbreds, clones or sibbed lines without control of pollination. *Synonyms*, **polycross** and **strain building.**

Multiple cross. A cross among many inbreds with pollination between desired lines *Synonym*, **composite cross.**

Crossing. It is an another name for hybridization defined as "the artificial cross-pollination between genetically unlike plants".

Cross-pollination See **pollination.**

Cytogenetics *n.* (Gk. *kytos*=hollow+*genesis*=descent). The combination of cytology and genetics in which the genetical data are interpreted in terms of chromosome structures.

Cytology *n.* (Gk. *kytos*=hollow+*logos*=discourse). The branch of biology which deals with the structure, function, properties, physiology, development and reproduction of cells.

Detassel. *v.* Removal of immature tassels of maize.

Diallel crossing. The crossing in which each of a number of males is crossed to each of a number of females so as to compare the breeding value of males.

Dichogamy *n.* (Gk. *dicha*=in two+*gamos*=marriage) The condition in which the male and female organs of a bisexual flower mature at different times insuring cross-pollination.

progenies raised by sowing the seed obtained from the F_1 self-fertilized or inter-crossed plants, and so on.

False heterosis. See **heterosis.**

Fertilization *n.* (L. *fertilis*=fertile). The union of two morphologically dissimilar male and female gametes.

Foreign seeds. Seed of weeds and crops other than the kind under consideration or being tested.

Foundation seed. The seed raised from breeder's stock seed on Seed Multiplication Farms under the guidance of technical staff and is genetically and physically pure. Indeed every seed produced on Seed Multiplication Farms is known as foundation seed.

Gamma garden. The place where the plants or insect pests are treated with gamma rays emitted from the source.

Geitonogamy *n.* (Gk. *geiton*=neighbour+*gamos*=marriage). The pollination between two neighbouring flowers on the same plant. This is found in monoecious type of plants and is genetically equal to self-pollination.

Genetics *n.* (Gk. *genesis*=descend. Bateson, 1906). The science of heredity and variation among related organisms.

Genofund. The term given by Zhukovsky (1970) to indicate the genetic source or gene pool for breeding (Refer Leppik's paper of 1970 on page 218).

Genotype *n.* (Gk. *genos*=race+*typos*=image, Johannsen, 1909). The genetical composition of an organism expressed in terms of genes as AABbCcDD, i.e., the sum total of its genes, both dominant and recessive.

Germination percentage. The percentage of the pure seed of the kind under consideration which produces normal seedlings.

Haploid. (Gk. *haploos*=single+*eidos*=form). The organism or generation having a single set (genome) of chromosomes, and is expressed as n, i.e., halved, reduced or haploid number.

Haploid apogamy. See **apogamy.**

Haploid parthenogenesis. See **parthenogenesis.**

Heredity *n.* Inherited characters transmitted by parents to progeny.

Heritability. The potentiality of an individual to inherit a particular trait in the offspring. It is equivalent to

additive genetic variance divided by the total phenotypic variance.

Herkogamy *n.* (Gk. *herkos*=a fence+*gamos*=marriage). A condition which enforces cross-pollination in bisexual flowers due to physical barriers between the stamen and stigma

Heterogamy *n.* (Gk *heteros*=other+*gamos*=marriage) A type of sexual reproduction in which the male and female gametes involved in fertilization are morphologically dissimilar. *Opp*, **isogamy.**

Heterosis *n.* (Gk *heteros*=different+*osis*=condition. Shull, [illegible]). Literally means a condition different from parents Genetically it is the increased vigour, growth, yield, or function of a hybrid over the parents that results from the crossing of genetically unlike organisms. *Synonym*, **hybrid vigour.**

Balanced heterosis True heterosis resulting from hybridization.

Mutational heterosis. Heterosis obtained from the creation of mutations in plants.

Pseudoheterosis. The false heterosis resulting from more favourable environmental and cultural practices

Heterostyly (Gk. *heteros*=different+*stylos*=styles). A condition which favours cross-pollination in bisexual flowers due to presence of male and female parts at different levels, i e, they are different in their lengths.

Homogamy *n* (Gk *homos*=one and the same+*gamos*=marriage). The condition in which the anthers and stigmas of bisexual flowers mature at the same time thus giving rise to self-pollination. *Opp*, **dichogamy.**

Host *n* (Gk *hostis*=stranger). A plant which nourishes the parasite.

Hybrid *n.* (L. *hybrida*=cross). The progeny of a cross between two or more individuals, plants or animals, of unlike genetical constitution. *Synonym*, **cross-breed.**

Hybridization. A method of crop improvement in which two or more plants of unlike genetical constitutions differing in one or more characters are crossed together.

Hybrid sterility. The sterility found in hybrids and caused by hybridization due to which the hybrids do not produce viable offsprings. The basis of hybrid sterility may be genic, chromosomal, or cytoplasmic.

Hybrid vigour. The increased vigour often exhibited by hybrid progenies. See **heterosis**

I_1, I_2, I_3. Symbols used to designate the first, second and third generations of inbreeding.

Immunity *n.* (L. *immunis*=free). Complete resistance against the disease or insect due to which, in spite of attack, the plant remains free from disease development.

Immunize *v* To induce the immunity in the host against a particular parasite

Improved seed. The genetically and physically pure seed of an improved crop variety. Its different categories are nucleus seed, breeder's stock seed, foundation seed, registered seed and certified seed.

Inbred. In plants, the progeny of either a single cross-pollinated plant obtained by selfing or two closely related plants obtained by inbreeding, and in animals. the product of inbreeding *Synonym*, **inbred line.**

Inbred selection. See **pure-line selection**

Inbred-variety cross. See **cross.**

Inbreeding. The mating of closely related organisms. In plants, it is done by artificial self-pollination, i e., selfing: and in animals, it is achieved by mating of closely related ones such as father-daughter, brother-sister, or mother-son matings.

Incompatibility Failure of fertilization, self or cross, due to hindrances which act between pollination and fertilization, e.g., morphological dissimilarity between pollen-tube and style, slow or deficient pollen-tube growth, too distant relationship between pollen and style or stigma. undesirable physiological effects, etc.

Incompatibility should not be confused with sterility which is due to sterile pollens and other genetical causes.

Incompatibility within the same variety prevents the self-pollination and promotes the cross-pollination

Induced mutations. The mutations artificially produced with the help of mutagens.

Inert matter. All foreign matters not seeds such as stones, sticks, sterile florets, chaffs, fungus bodies, and pieces of seeds not more than one half of the original seeds.

Inheritance The transmission of hereditary characters from parents to progeny.

Integument *n* (L *integumentum*=covering). Covering of ovule which later on becomes the seed coat

Intergeneric *adj.* (L *inter*=between+*genus*=kind) The hybridization between the plants belonging to two different *genera*

Intrageneric *adj* (L *intra*=within+*genus*=kind) The hybridization between the plants belonging to two different species within the same genus. *Synonym,* **interspecific.**

Intraspecific *adj* (L. *intra*=within+*species*=particular kind+*facere*=to make). The hybridization between two varieties of the same species *Synonym,* **intervarietal.**

Intravarietal *adj.* (L *intra*=within + *varius*=diverse). The hybridization between two plants of the same variety.

Introduction. See **plant introduction.**

Introgressive hybridization The hybridization in which the characters of one species infilter into another by automatic backcrossing in nature

Ion Electrically charged atom or group of atoms formed by dissociation (ionization) of a molecule

Ionization. A physical term applied to the process by which ions dissociate from a molecule.

Ionizing radiation Any of the high energy radiations that displaces electrons from neutrons It destroys the balance between the negative charge of the electrons and the positive charge of the atomic nucleus thus making ions out of atoms

Irradiation *n* (L *in*=into+*radius*=rays) The treatment of

plant or plant material, i.e., seeds, seedlings, pollens, etc., with radiations.

Irradiation breeding The creation of mutations by subjecting the plants or seeds to radiations and their utilization for crop improvement.

Isogamy *n.* (Gk. *isos*=equal+*gamos*=marriage). A type of sexual reproduction in which the male and female gametes involved in reproduction are morphologically similar. It is usually found in lower plants like algae and fungi. *Opp.*, **heterogamy.**

Klendusity. See **disease escape.**

Lamarckism. The doctrine of Lamarck pertaining to inheritance of acquired characters.

Local variety. It is a mixture of different types and is well adapted to the local environment. It is endemic to an area with its origin going back several hundred years *Synonyms*, **Land variety** and **old variety.**

Lysenkoism. The doctrine of Russian scientist Lysenko who favoured that acquired characters are inherited.

Mass selection. The selection of a number of plants, heads or seeds phenotypically superior in characters from the field population, harvesting and bulking their produce together for sowing the next year's crop, and repeating this process till the desired improvement is achieved.

Mature plant resistance. A term particularly applied to the resistance to stem rust from heading to maturity.

Mechanical seed sample The original seed sample obtained from the market for seed testing purposes.

Megagametogenesis *n.* (Gk. *megas*=great, i e., female+*gametes* =gametes+*genesis*=development). The process of female gamete (megaspore) formation.

Microgametogenesis *n.* (Gk. *micros*=small, i e, male+*gametes* =gametes+*genesis*=development). The process of male gamete (microspore) formation.

Monoecious *adj.* (Gk. *monos*=single+*oikos*=house). The unisexual condition in which the male (staminate) and female (pistillate) flowers are separate but on the same plant.

Mule Male or female hybrid offspring of a jack (male ass) and a mare (female horse). The mule is usually sterile, sturdy and resembles more to ass than the horse

Multiple cross. See **cross.**

Mutagen. Any substance, chemical, or physical, that induces mutations in organisms. *Synonym*, **mutagenic agent**

Mutant. Any organism, plant or animal which has originated or acquired a heritable variation as a result of mutations.

Mutation *n.* (L *mutare*=to change De Vries, 1901). In general sense, the sudden heritable changes in an organism other than those due to Mendelian segregation and recombination. Thus it includes all kinds of hereditary changes In strict sense, the sudden heritable and invisible changes, physical or chemical, within the individual genes Now-a-days, the use of mutation in strict sense is of more common application.

Mutation breeding. The creation of mutations at will and their utilization for crop improvement and production of new superior crop varieties

Mutational heterosis. See **heterosis**

Mutilation *n* (L *mutilus*=to maim) Loss of an organ of an organism.

n Symbol used to designate the haploid, i e , single number of chromosomes See **haploid**

2n. Symbol used to designate the diploid, i e , double number of chromosomes. See **diploid**

Natural selection (Charles Darwin and A R. Wallace, 1858). A process of evolution, i.e., a selection operating automatically in nature in which the fittests survive and rest wipe out. See **selection**

Natural vegetative reproduction See **vegetative reproduction.**

Non-recurrent parent. See **donor parent**

Nucleus seed The original seed produced for the first time by the plant breeder. It is cent per cent pure in all genetical and physical qualities and used as a parent for the multiplication of breeder's stock seed.

Official seed samples. The samples which are collected by seed control or seed law enforcement officer. They are submitted to the seed laboratory to determine if a seed lot being offered for sale whether meets the requirement of seed act or not.

Oospore *n.* (Gk. *oion*=egg+*sporos*=seed). A fertilized egg or immediate product of fertilization which after passing through different stages of development gives rise to the embryo of seed.

Overdominance hypothesis. The hypothesis proposed by Shull and East in 1908 to explain the cause of hybrid vigour as "the heterozygosity".

P_1 A symbol used to designate the parental generation of a cross.

Parthenocarpy *n* (Gk. *parthenos*=virgin+*karpos*=fruit). The formation of seedless fruits without fertilization of ovule as in banana and pineapple.

Parthenogenesis. A type of apomixis in which the embryo develops from the egg-cell or male gamete without fertilization and with or without meiosis It is subdivided into two types :

Haploid parthenogenesis. Meiosis takes place in egg-cell and then embryo develops. *Synonym*, **generative parthenogenesis.**

Diploid parthenogenesis. The meiosis is absent and thus the embryo develops from the diploid egg-cell. *Synonym*, **somatic parthenogenesis.**

Pathogen. A disease causing organism.

Pedigree method A hybridization method used in self-pollinated crops which in the hybrid progenies are maintained separately in F_2 and succeeding generations up to F_6, and the best hybrids are bulked at the end to constitute the improved variety.

Pedigree selection. See **pure-line selection**

Phenotype *n* (Gk *phainein*=to appear+*typus*=image. Johannsen, 1909). The external appearance of an organism by the interaction of genotype with environment.

Physiological resistance A type of disease resistance due to physiological characters

Phytology *n* (Gk *phyton*=plant+*logos*=discourse). Science dealing with the study of plants *Synonym*, **botany.**

Phytopathology *n* (Gk. *phyton*=plant+*pathos*=disease+*logos*=discourse) The science of plant diseases and their control. See **plant pathology.**

Plant breeding. The applied branch of botany dealing with the crop improvement and production of new improved crop varieties far better than original in all aspects.

Plant introduction The process of introducing the plants from their growing locality to a new locality having a different climate.

Plant pathology The applied branch of botany dealing with the plant diseases and their control. *Synonym*, **phytopathology.**

Pollination. The transference of pollens to the stigma in angiospermic plants and to micropyle in gymnospermic plants It is divided into different types :

Natural or open pollination. Automaticallv taking place in flowers in nature

Self-pollination The transfer of pollens to the stigma of the same flower

Cross-pollination. The transfer of pollens to the stigma of another flower present on a different plant.

Artificial or **controlled pollination.** The man-made pollination, i e., it is the pollination artificially done by human being in the desired combination

Selfing. Artificial self-pollination within the desired plant

Crossing Artificial cross-pollination between the desired plants.

Polyallele crossing : The crossing of several inbred lines with each other to determine their respective combining ability

Polycross. See **synthetic cross**

Polyploid *adj*. (Gk. *polys*=many+*aploos*=onefold+*eidos*=form). A cell, tissue or an organism having more than diploid num-

ber of chromosomes, and repectively is called triploid, tetraploid, pentaploid, etc.

Progeny. The offsprings of a particular mating.

Progeny selection. See **pure-line selection.**

Progeny test. A test carried out by growing the progenies so as to evaluate the genotype of parent.

Protandry. See **dichogamy**

Protogyny See **dichogamy.**

Pseudoheterosis. See **heterosis.**

Pure-line (Johannsen, 1903). The progeny of single self-fertilised homozygous plant

Pure-line selection The isolation of desirable homozygous plants from the mixed population and multiplying the same without contamination to release as improved variety. *Synonyms*, **head-to-row selection, progeny selection, pedigree selection, single-line selection, inbred selection,** etc.

Pure seed. The seed true to its kind or variety.

R_1, R_2, R_3 The symbols used to designate first, second and third irradiation generations

Radiations The movement of energy, which is given off by radioactive isotopes in either particles or wave form through a space.

Radioisotopes The unstable atoms which tend to split or to give off particles or energy thereby achieving stability. *Synonym*, **radioactive isotopes.**

Real value of seed The value of a seed sample in comparison to another defined as "the percentage of pure germinating seeds" and it is calculated by the formula, R. V.=(Purity% ×Germination%)÷100.

Reciprocal hybrids. Two hybrids produced by crossing the same parents but the male of first is used female in the another and similarly the female of first is used male in another, such as A×B and B×A.

Recurrent parent. A commercially desirable variety lacking into one or two good characters like disease or insect resis-

tance which is used as female first and then as male in each generation and backcrossed again and again to hybrids with a view to transfer its all characters into the hybrids possessing disease resistance character. *Synonyms*, **recipient parent** and **backcross parent.**

Registered seed. The progeny of foundation or registered seed itself produced by the Registered Seed Growers in such a way as to maintain the satisfactory genetic identity and purity. It is normally grown for production of certified seed.

Reproduction *n.* (L. *re*=again+*producere*=to lead forth). The process of propagation and perpetuation in organisms by which they give rise to offsprings of similar kind. It is of various types :

Sexual reproduction. Both male and female parents' sexes are involved.

Asexual reproduction. Only one parent's sex is involved and is found in lower types of plants.

Vegetative reproduction Propagation is with the help of vegetative parts of the plant body and never found in animals

Resistance. See **disease resistance.**

S_0 The symbol used to designate the original generation of selfing.

S_1, S_2, S_3. The symbols used to designate the first, second and third generations of selfing. S_1 is obtained by sowing the seeds of S_0 plants, S_2 by sowing the seed of S_1 plants and so on for S_3, S_4, etc.

Seed testing. The analysis of seed sample for judging its quality.

Selection. Any process which favours the survival and propagation of certain individuals possessing desirable characters. Its various forms are :

Natural selection. (Charles Darwin and A R Wallace, 1858). The process of evolution automatically operating in nature in which the fittests survive and rest wipe out

Artificial selection. Selection practised by human being to choose certain plants for the purpose of having better crop from the mixed population where the individuals differ in characters. The various types of common selections of this kind are **mass selection, pure-line selection and clonal selection.**

Selfing. Artificial self-pollination. See **pollination.**

Self-pollination. See **pollination.**

Service seed sample. The sample submitted by a cultivator, seedsman, co-operative or seed firm for determining the quality of seed which he is dealing.

Sexual reproduction. Reproduction involving the union of male and female gametes from both the parents.

Isogamy. Uniting male and female gametes are morphologically similar.

Heterogamy. Uniting male and female gametes are morphologically dissimilar.

Single cross. See **cross.**

Single-line selection Synonym for 'pure-line selection'.

Sterility *n.* The condition of being infertile or incapable of reproducing.

Strain A group of plants within the variety which differs from it in one or more genetic or physiological characters other than main morphological characters.

Susceptibility. The inability of plants to defend or overcome the attack of pathogen. See **disease resistance.**

Synergids *n.* (Gk. *synergos*=co-operation). Two cells lying with egg-cell at the micropylar end of embryosac

Synthetic cross. See **cross.**

Three-way cross. See **cross.**

Tolerance. See **disease endurance.**

Top-cross. See **cross.**

Trait. A loose synonvm for 'character'.

Trier. A mechanical device for drawing or taking seed samples from bags or heaps

Triple-fusion Union of male gamete with definitive nucleus. Genotypically nucleus is 2n and male gamete n. Their fusion results in 3n structure and, therefore, it is called triple-fusion.

Variety. A sub-division of species defined as "a group of plants within a species which are uniform in characters". *Synonyms,* **cultivar** and **cultigen.**

Vegetative reproduction. The reproduction in which the new plants are produced with the help of vegetative parts of the plant body.

Natural vegetative reproduction. A vegetative portion of plant body gets detached off automatically and falls on the ground giving rise to new plants, such as rhizomes, bulbs, corns, etc.

Artificial vegetative reproduction. The vegetative parts of the plant body are removed by human being in desired ways and used to raise new plants such as cuttings, layering, gootee and grafting.

X_1, X_2, X_3. The symbols used to designate the first, second and third generations of X-ray treated plants or seeds

APPENDIX I

SEED TESTING LABORATORIES IN INDIA (1968)

1. Central Seed Testing Laboratory, Division of Botany, I.A R.I , New Delhi.
2. Seed Testing Laboratory, Agricultural Research Institute, Rajendranagar, Hyderabad, Andhra Pradesh.
3. Seed Testing Laboratory, Agricultural Research Station, Kamrup, Gauhati, Assam.
4. Seed Testing Laboratory, Patna, Bihar.
5. Seed Testing Laboratory, Athva Lines, Surat, Gujarat.
6. Seed Testing Laboratory, Department of Agriculture, Mahasu, Distt. Solan, Himachal Pradesh.
7. Seed Testing Laboratory, Lal Mandi, Srinagar, Jammu and Kashmir.
8. Seed Testing Laboratory, Agricultural Research Station, Pattambi, Distt. Palghat, Kerala.
9. Seed Testing Laboratory, Botany Division, College of Agriculture, Nagpur, Maharashtra.
10. Seed Testing Laboratory, College of Agriculture, Coimbatore, Tamil Nadu.
11. Seed Testing Laboratory, Department of Agriculture, Jabalpur, Madhya Pradesh.
12. Seed Testing Laboratory, Horticulture Department, Lal Bagh, Bangalore, Mysore
13. Seed Testing Laboratory, Department of Agriculture, Bhubaneshwar-3, Orissa
14. Seed Testing Laboratory, College of Agriculture, Punjab Agricultural University, Ludhiana, Punjab.
15. Seed Testing Laboratory, Regional Research Station, Durgapura, Jaipur, Rajasthan.
16. Seed Testing Laboratory, Department of Agriculture, Kanpur, Uttar Pradesh.
17. Seed Testing Organization, 238, Netaji Subhas Chandra Bose Road, Calcutta-40, West Bengal.

APPENDIX II

CULTIVATED PLANTS OF INDIA

C=cross-pollination, O. C =often cross-pollination, O. S.=often self-pollination, and S.=self-pollination

S. No.	*Name of the Crop (Family)*	*Pollination*	*Botanical Name*	*Chromosome Number 2n=*	*Vernacular or Common Name*
1	2	3	4	5	6
			I Cereals		
1.	Barley (*Gramineae*)	S	*Hordeum vulgare* L.	14	Jau
2.	Buckwheat (*Polygonaceae*)		*Fagopyram esculentum* L.	16	Kutu
3.	Maize, Corn (*Gramineae*)	C	*Zea mays* L	20	Makka, Bhutta
4.	Oat (*Gramineas*)	S	*Avena sterilis* L var *Culta*, or *Avena byzantina* Koch	42	Jai

1	2	3	4	5	6
5.	Rice, Paddy (*Gramineae*)	O.S.	*Oryza sativa* L	24	Chawal, Dhan
6.	Wheat (*Gramineae*)	S.	*Triticum spp.*	.	Gehun
	(i) Bread wheat	S.	*Triticum aestivum* L., *Triticum sativum* L., or *Triticum vulgare* Host.	42	Gehun
	(ii) Dwarf wheat	S.	*Triticum sphaerococcum* Pers.	42	Gehun
	(iii) Durum or Macaroni wheat	S.	*Triticum durum* Desf.	28	Gehun
	(iv) Emmer wheat	S.	*Triticum dicoccum* Schubl.	28	Gehun
	(v) Rivet wheat	S.	*Triticum turgidum* L.	28	Gehun
			II. Millets		
1.	Barnyard or Japanese millet (*Gramineae*)	O.S.	*Echinochloa frumentacea* Link., *Echinochloa colona* Link, or, *Panicum frumentacea* Roxb.	36,56	Sanwa
2.	Cockspur Grass (*Gramineae*)	S.	*Echinochloa crusgalli* Beauv., *Panicum crusgalli* L., *Echinochloa stagnina* Beauv.,	36,42, 48,54	Dal, Banti, Bhatta, Bovar

1	2	3	4	5	6
3	Common, Hog, Proso, Broom corn or French millet (*Gramineae*)	S.	*Panicum miliaceum* L.	36	China, Bariri
4.	Finger millet (*Gramineae*)	O.S.	*Eleusine coracana* Gaertn.	36	Ragi, Marua
5	Fox-tail or Italian millet (*Gramineae*)	S.	*Setaria italica* Beauv.	18	Kangni
6.	Job s tear millet (*Gramineae*)	.	*Coix lachryma-jobi* L.	20	Gurgur, Kasai, Shankru
7.	Kodo millet (*Gramineae*)	S.	*Paspalum scrobiculatum* L.	40	Kondon, Pakodi
8	Little millet (*Gramineae*)	O.S.	*Panicum miliare* lam.	36	Kutki, Sanwa
9	Pearl millet (*Gramineae*)	O.C.	*Pennisetum typhoides* S. & H , or *Pennisetum typhoideum* L Rich.	14	Bajra, Cumbu
10	Sorghum, or Great millet (*Gramineae*)	O.S.	*Andropogon sorghum* Brot., or *Sorghum vulgare* Pers	20	Jowar

1	2	3	4	5	6
	III Fibre Crops				
1	Cotton (*Malvaceae*)	..	*Gossypium spp.*		Kapas, Rui
	(i) Asiatic cotton	O.S	*Gossypium arboreum* L.	26	,,
	(ii) Broach cotton	O S	*Gossypium herbaceum* L	26	,,
	(iii) Upland cotton	O.S.	*Gossypium hirsutum* L	52	,,
	(iv) Egyptian or Sea Island cotton	O.S.	*Gossypium barbadense* L	52	,,
2	Deccan or Madras hemp (*Malvaceae*)	O.C.	*Hibiscus cannabinus* L	36	Patsan, Ambari
3	Javan Jute or Rozelle (*Malvaceae*)	O.S.	*Hibiscus sabdariffa* L	36	Lal ambari, Patwa
4	Jew's mallow (*Tiliaceae*)	.	*Corchorus olitorius* L	14	Koshta, Mithapat
5.	Jute (*Tiliaceae*)		*Corchorus capsularis* L.	14	Patt

1	2	3	4	5	6
6.	Kantala (*Agavaceae*)	.	*Agave cantala*	90	Ghaipat, Kethi
7	Sisal Hemp (*Agavaceae*)	..	*Agave sisalana* Perrine	138	..
8.	Sunn or Bombay hemp (*Papilionaceae*)	S.	*Crotalaria juncea* L.	16	San, Patua
			IV. Sugar and Starch Crops		
1.	Potato (*Solanaceae*)		*Solanum tuberosum* L.	48	Alu
2.	Sugar beet (*Chenopodiaceae*)	C.	*Beta vulgaris* L.	18	Chukandar
3.	Sugarcane (*Gramineae*)	C.	*Saccharum spp.*	.	Ganna, Santha, Ekh
	(i) Kans grass	C.	*Saccharum spontaneum* L.	48-128	Kans, Sarkanda
	(ii) Sugarcane	C.	*Saccharum officinarum* L.	80	Ganna
	(iii) Sugarcane	C.	*Saccharum barberi* Jesweit.	82-124	Ganna
	(iv) Sugarcane	C.	*Saccharum sinense* Roxb.	42-114	Ganna

1	2	3	4	5	6
4.	Tapioca (*Euphorbiaceae*)	..	*Manihot utilissima* Pohl or, *Manihot esculenta* Crantz	36	Tapioca
			V. Oilseeds		
1.	Carang pongam, or Indian Beech (*Papilionaceae*)	.	*Pongamia glabra* Vent., or *Galedupa pinnata* Lam.	20,22	Pongam
2.	Castor (*Euphorbiaceae*)	C.	*Ricinus communis* L.	20	Arand
3.	Coconut (*Palmae*)	O.C	*Cocos nucifera* L.	32	Nariyal
4.	Groundnut or Peanut (*Papilionaceae*)	S.	*Arachis hypogaea* L.	40	Mungphali
5.	Linseed or Flax (*Linaceae*)	O S.	*Linum usitatissimum* L.	30,32	Alshi
6.	Mahua oil seed (*Sapotaceae*)		*Madhuca butyracea*, or *Madhuca indica*	24	Mahua
7.	Mowra-fat or Mahwah (*Sapotaceae*)		*Madhuca latifolia*, or *Bassia latifolia*	24	Mahua

1	2	3	4	5	6
8.	Niger (*Compositae*)	C.	*Guizotia abyssinica* Cass.	30	Ramtil
9.	Rape and Mustard (*Cruciferae*)	.	*Brassica spp.*	..	..
	(i) Black mustard	C.	*Brassica nigra (sinapis)* Koch.	16	Banarasi Rai Asal Rai
	(ii) Brown sarson	C.	*Brassica campestris* var. *dichotoma*	20,32	Sarson
	(iii) Indian mustard	..	*Brassica juncea* Cass.	36	Rai
	(iv) Indian rape	C	*Brassica campestris* var. *toria* Dutch.	20	Toria
	(v) Leaf mustard	.	*Brassica juncea* var. *cuneifolia* *B. rugosa* var. *cuneifolia* Prain.	..	Pahadi Rai
	(vi) Rape	C.	*Brassica napus* L.	38	Tori
	(vii) White mustard	C.	*B hirta* Moench. or *B. alba*	..	Safed Rai
	(viii) Yellow Sarson or Indian Colza	C.	*B. campestris* var. *sarson* Prain.	20	Pili sarson
10.	Rocket Salad (*Cruciferae*)	..	*Eruca sativa* Mill.	22	Taramira

1	2	3	4	5	6
11.	Safflower (*Compositae*)	C.	*Carthamus tinctorius* L.	24	Kusum, Kardi
12.	Sesame or Gingelly (*Pedaliaceae*)	S	*Sesamum indicum* L., or *Sesamum orientale* L.	26	Til
13.	Sunflower (*Compositae*)	C.	*Helianthus annuus* L	34	Surajmukhi
			VI. Fodder Crops		
1.	Anjan grass (*Gramineae*)		*Pennisetum orientale* Link.	.	Anjan ghas
2.	Bermuda or Bahama grass (*Gramineae*)		*Cynodon dactylon* Pers.	36,40	Doob
3.	Blue grass (*Gramineae*)		*Panicum antidotale* Retz.	18	Neelan ghas
4.	Bunch grass (*Gramineae*)		*Cenchrus ciliaris*	32,36, 40,54	
5.	Bur clover (*Papilionaceae*)	S	*Medicago hispida* Gaertn.	14,16	

1	2	3	4	5	6
6	Calopo grass (*Papilionaceae*)	.	*Calopogonium mucunoides*	36	..
7.	Canary grass (*Gramineae*)		*Phalaris canariensis* L.	12	.
8	Carpet legume (*Papilionaceae*)	S.	*Dolichos lablab* var *lignosus* or *Lablabniger* Medik	22	Sem
9.	Centro (*Papilionaceae*)		*Centrocema pubescens*	20	.
10.	Cluster bean (*Papilionaceae*)	S	*Cyamopsis tetragonoloba* Taub	14	Guar
11.	Common Vetch, Tare (*Papilionaceae*)	S	*Vicia sativa* L.	12	Bakla
12.	Egyptian clover (*Papilionaceae*)		*Trifolium alexandrinum* L	16	Berseem
13.	Guinea grass (*Gramineae*)	.	*Panicum maximum* Jacq	18,32, 36,48	Guinea ghas
14	Hubam clover (*Papilionaceae*)	.	*Melilotus alba* var. *annua*	16,24	Ban methi.

1	2	3	4	5	6
23.	Persian clover (*Papilionaceae*)	.	*Trifolium resupinatum* L.	16	Shatala
24.	Rhodes grass (*Gramineae*)	..	*Chloris gayana* Kunth	20	Rhodes ghas
25.	Rhodesian Timothy (*Gramineae*)		*Setaria sphacelata* S. & H	36,54	..
26.	Soybean (*Papilionaceae*)	S.	*Glycine max* L. *Glycine hispida* Maxim.	40 40	Soybean Soybean
27.	Star grass (*Gramineae*)		*Cynodon plectostachyum* Pilger.	18,54	Star ghas
28.	Stylo (*Papilionaceae*)	.	*Stylosanthes gracillis*	..	..
29.	Sudan grass (*Gramineae*)		*Sorghum sudanense* Stapf.	20	Sudan ghas
30	Sunflower (*Compositäe*)	C.	*Helianthus annuus* L ,	34	Surajmukhi
31.	Thin napier (*Gramineae*)	.	*Pennisetum polystachyon*	54	..

1	2	3	4	5	6
2.	Broad, Windsor or Horse bean (*Papilionaceae*)	O.S.	*Vicia faba* L., or *Faba vulgaris* Moench	12,14	Bakla bean
3.	Cluster bean (*Papilionaceae*)	S	*Cyamopsis tetragonoloba* Taub., *Cyamopsis psoraloides* DC.	14	Guar
4.	Cowpea (*Papilionaceae*)	S	*Vigna sinensis* Savi., *Vigna unguiculata* L. or *Dolichos sinensis* L.	22,24	Chaunla, Lobia
5.	Dew gram or Moth bean (*Papilionaceae*)	S.	*Phaseolus aconitifolius* Jacq , *P. trilobus* Wall, or *Dolichos dissectus* Lam.	22	Moth
6.	Double bean (*Papilionaceae*)	S.	*Phaseolus lunatus* L., or *Phaseolus inamoenus* Blanco.	22	
7.	Gram, Bengal gram, or Chick pea (*Papilionaceae*)	S	*Cicer arietinum* L	16	Channa
8.	Grass pea (*Papilionaceae*)	O.S.	*Lathyrus sativus* L.	14	Keshari

1	2	3	4	5	6
9	Green gram, Mung bean (*Papilionaceae*)	S.	*Phaseolus aureus* Roxb, *P. aureus* var *radiatus* Roxb.	22	Mung
10.	Goa bean (*Papilionaceae*)	.	*Psophocarpus tetragonolobus* DC.	..	Makhmali sem
11.	Horse gram (*Papilionaceae*)	S.	*Dolichos biflorus* Roxb.	24	Kultha
12.	Hyacinth bean, Indian, or Carpet bean (*Papilionaceae*)	S.	*Dolichos lablab* L., or *Dolichos sudanensis* Hort.	22,24	Sem, Balol
13.	Kidney, French, Dwarf, Haricot, or String bean (*Papilionaceae*)	..	*Phaseolus vulgaris* L.	22	Vilaiti sem
15.	Lima bean (*Papilionaceae*)	S.	*Phaseolus limensis* Macf.	.	..
16	Lentil (*Papilionaceae*)	S.	*Lens esculenta* Moench., *Lens culinaris* Medic., or *Ervum lens* L.	14	Masur
17.	Pea : Garden (*Papilionaceae*)	S.	*Pisum sativum* L.	14	Mattar

1	2	3	4	5	6
18.	Pea. Field (*Papilionaceae*)	S.	*Pisum arvense* L.	14	Mattar
19.	Pigeon pea or Red gram (*Papilionaceae*)	O.C.	*Cajanus cajan* Millsp., or *Cajanus indicus* Spreng.	22,44,66	Arhar, Tur
20.	Rice bean (*Papilionaceae*)		*Phaseolus calcaratus* Roxb., or *Vigna luteola* Merr.	22	Sim
21.	Scarlet runner bean (*Papilionaceae*)		*Phaseolus coccineus* L., *P multiflorus* Lam , or *Lipusa multiflora* Alef.	22	Uri, Sim
22.	Soybean (*Papilionaceae*)	S	*Glycine max* Merr., *G. soya*, *Soja hispida* Maxim., or *Dolichos soja* L	40	Soybean, Bhat
23.	Sword bean (*Papilionaceae*)	..	*Canavalia gladiata* DC	22,44	Bara Sem
24.	Velvet bean (*Papilionaceae*)	S.	*Mucuna deeringiana* Brot.	..	..
25.	Yam bean (*Papilionaceae*)	.	*Pachyrrhizus erosus* Urbn., *P angulatus* Rich , *Cacara erosa* Kuntze., or *Dolichos erosus* L.	22	Sakalu

1	2	3	4	5	6
	Bulbs:				
1.	Garlic (*Liliaceae*)	..	*Allium sativum* L.	16	Lasun
2.	Onion (*Liliaceae*)	C.	*Allium cepa* L.	16,32	Piaz, Pyaz
	Cole crops:				
1.	Cabbage (*Cruciferae*)	C.	*Brassica oleracea* L. var. *capitata* L. *B. oleracea* L. var. *bullata* DC.	18,36,72	Band gobee
2.	Cauliflower (*Cruciferae*)	C.	*B. oleracea* L. var. *botrytis* L., *B. cauliflora* Gars , or *B. botrytis* Mill.	,,	Phul gobee
3.	Knol-khol (*Cruciferae*)		*B. caulorapa* Pasq., *B. oleracea* var. *gongylodes* L., or *B. oleracea* var. *caulorapa* DC.	,,	Ganth gobee
	Cucurbitaceous vegetables:				
1.	Bitter gourd (*Cucurbitaceae*)		*Momordica charantia* L.	22	Karela

1	2	3	4	5	6
2.	Bottle gourd, Calabashg (*Cucurbitaceae*)		*Lagenaria siceraria* Standl., *L. leucantha* Rusby., L *vulgaris* Ser , *Cucurbita siceraria* Molina , or *Cucurbita leucantha* Duchesne	22	Lauki, Ghia
3.	Cucumber (*Cucurbitaceae*)	C.	*Cucumis sativus* L.	14	Khira Kakri, Sasa
4.	Ghiya tori, Smooth, Sponge, or Dish cloth gourd (*Cucurbitaceae*)		*Luffa cylindrica* Roem , *Luffa aegyptiaca* Mill , or *Luffa pentandra* Roxb.	26	Ghiya tori
5.	Kakora (*Cucurbitaceae*)	..	*Momordica cochinchinensis* Spreng. *Momordica mixta* Roxb., or *Momordica dioica* Roxb.	28	Bhat Karela
6.	Little gourd, or Kovai fruit (*Cucurbitaceae*)	.	*Coccinia cordifolia* Cogn , *Coccinia indica* W. & A., or *Cephalandra indica* Naud	24,36	Ole kapi, Kundru
7.	Long melon, or Tar (*Cucurbitaceae*)		*Cucumis melo* L. var. *utilissimus* D & H.	..	Kakri
8.	Musk melon (*Cucurbitaceae*)	C	*Cucumis melo* L	24	Kharbuja

1	2	3	4	5	6
9.	Pointed gourd, or Potol (*Cucurbitaceae*)	C.	*Trichosanthes dioica* Roxb.	22	Parwal
10.	Pumpkin or Red gourd (*Cucurbitaceae*)	C.	*Cucurbita moschata* Duch.	24,40,48	Mith a kaddu, Lal Kumra
11.	Ridge gourd (*Cucurbitaceae*)	..	*Luffa acutangula* Roxb.	26	Tori, kali tori, Jhinga
12.	Round gourd (*Cucurbitaceae*)	..	*Citrullus vulgaris* S. var. *fistulosus* Stocks	..	Tinda
13.	Snake gourd (*Cucurbitaceae*)	C.	*Trichosanthes anguina* L., or *T. colubrina* Jacq.	22	Chichinda
14.	Squash, Christophine, Pipinella, and Chayote (*Cucurbitaceae*)	C.	*Sechium edule* Sw.	24	Cho cho, Nada, Juani
15.	Summer Squash (*Cucurbitaceae*)	..	*Cucurbita pepo* L., *C. verrucosa* L., or *C. polymorpha* Duch.	40	Halwa kaddu, Vilaiti tinda
16.	Wax, white, or ash gourd (*Cucurbitaceae*)	..	*Benincasa cerifera* Savi, or *B. hispida* Cogn.	24	Kohla Petha Gol kaddu.

1	2	3	4	5	6
17.	Water melon (*Cucurbitaceae*)	C.	*Citrullus vulgaris* Schrad.	22	Tarbuj, Mattira.
18.	Winter squash (*Cucurbitaceae*)		*Cucurbita maxima* Duch.	24,40	Sitafal
	Leafy vegetables :				
1.	Agathi, or Humming bird (*Papilionaceae*)	.	*Sesbania grandiflora* Pers , *Agati grandiflora* Desv., or *Robinia grandiflora*	24	Agati
2.	Amaranth (grain) (*Amaranthaceae*)		*Amaranthus caudatus* L., *A. paniculatus* L., or *A frumentaceus* Buch-Ham.	32	Ramdana, Chulai, Anardana
3.	Amaranth (Prickly) (*Amaranthaceae*)	..	*Amaranthus spinosus* L	34	Kantewali Chulai
4	Amaranth (tender) (*Amaranthaceae*)	..	*Amaranthus tricolor* L., *A. melancholicus* L., or *A. gangeticus* L.	34	Lal sag, Lal Chulai
5.	Amaranth (green) (*Amaranthaceae*)	..	*Amaranthus viridis* L.	34	Chulai

1	2	3	4	5	6
33	Tikka sag (*Capparidaceae*)		*Crataeva religiosa* Frost.	26	Varuna
34	Water cress (*Cruciferae*)		*Nasturtium officinale* R. Br	16,32	Brahmi sag, Halim
	Pod, Fruit and Seed vegetables :				
1	Bitter gourd	..	See Cucurbitaceous veg.	..	..
2.	Bottle gourd	.	See Cucurbitaceous veg.	..	..
3	Brinjal or Egg plant (*Solanaceae*)	S.	*Solanum melongena* L.	24	Bengun
4	Broad bean	..	See Beans and pulses under veg.	..	..
5.	Calabash gourd	..	See Cucurbitaceous veg.	..	..
6.	Chayote	..	See Cucurbitaceous veg.	..	..
7	Chillies, Red pepper, or Bell pepper (*Solanaceae*)	O.S.	*Capsicum frutescens* L., *Capsicum annuum* L., or *Capsicum baccatum* L.	24	Hari mirch, Lal mirch
8	Cluster bean (*Papilionaceae*)	S.	*Cyamopsis tetragonoloba* Taub., or *C. psoraloides* DC.	14	Guar

1	2	3	4	5	6
20.	Jamaica sorrel (*Malvaceae*)	..	*Hibiscus sabdariffa* L.	36	Patwa
21.	Kakora	..	See Cucurbitaceous veg.	..	..
22.	Kali tori	..	,,	.	.
23.	Kateli (*Solanaceae*)	..	*Solanum indicum* L. var. *multiflora* Wright.	24	Kandan, kathiri
24.	Kidney bean	.	See Beans and Pulses under veg.	.	
25.	Kovai fruit	..	See Cucurbitaceous vegetables		..
26.	Lady's finger (*Malvaceae*)	O S.	*Abelmoschus esculentus* Moench. or *Hibiscus esculentus* L.	72,120, 130,132	Bhindi
27	Methi or Fenugreek	.	See Leafy vegetables	..	..
28.	Plantain (*Musaceae*)		*Musa sapientum* L.	22,44	Kachha kela
29.	Pumpkin		See Cucurbitaceous veg.	..	..
30.	Radish		See Underground veg	.	..

1	2	3	4	5	6
2	Arvi, or Arum or Elephant ear. (*Araceae*)	.	*Colocasia esculenta* L., or *C. antiquorum* Schott.	28,36,48	Arvi
3	Beet root (*Chenopodiaceae*)	C	*Beta vulgaris* L.	18	Chukundar
4	Carrot (*Umbelliferae*)	C.	*Daucus carota* L	18	Gajar
5.	Chayote	..	See Cucurbitaceous veg.	.	..
6	Elephant foot yam (*Araceae*)	.	*Amorphophallus campanulatus* B.	26,28	Zaminkand
7.	Ginger (*Zingiberaceae*)		*Zingiber officinale* Rosc.	22	Adrak
8.	Knol-khol	.	See Cole crops		..
9.	Leek (*Liliaceae*)		*Allium porrum* L.	32	Vilaiti pyaz Vilaiti lasun
10.	Madagascar potato (*Labiatae*)		*Coleus rotundifolius* Poir., *C. parviflorus* Benth, or *C. tuberosus* Benth.	..	Koorkan

1	2	3	4	5	6
20	Yam (lesser) (*Dioscoreaceae*)	.	*Dioscorea esculenta* Burkill.	.	Suthani
21.	Yam bean (*Papilionaceae*)		*Pachyrrhizus erosus* Urban., *P. angulatus* Rich., *Dolichos erosus* L., or *Cacara erosa* K.	22	Sakalu
		VIII.	**Spices and Condiments**		
1.	Ajmud (*Umbelliferae*)	.	*Trachyspermum roxburghianum* Sp., or *Carum roxburghianum* Benth	18	Radhuni
2.	Aniseed (*Umbelliferae*)	..	*Pimpinella anisum* L	18,20	
3.	Areca or Betel nut (*Palmae*)	C	*Areca catechu* L	32	Supari
4.	Betel leaf (*Lauraceae*)		*Cinnamomum tamala* Nees.	24	Tejpat
5.	Betel leaf, or B. pepper (*Piperaceae*)	C	*Piper betle* L.	32	Pan
6.	Black cumin (*Ranunculaceae*)	..	*Nigella sativa* L	12	Kala jeera, kalounji

1	2	3	4	5	6
7.	Black mustard (*Cruciferae*)	..	*Brassica nigra* Koch	16	Kali rai
8.	Black pepper (*Piperaceae*)	C.	*Piper nigrum* L.	128	Kali mirch, Gole mirch
9.	Cardamom (Lesser) (*Zingiberaceae*)	..	*Elettaria cardamomum* Maton	48,52	Chhoti elaichi
10.	Cardamom (greater) (*Zingiberaceae*)	..	*Amomum subulatum* Roxb.	..	Bari elachi
11.	Cardamom (Aromatic) (*Zingiberaceae*)		*Amomum aromaticum* Roxb.	..	
12.	Chillies (*Solanaceae*)	O.S.	*Capsicum frutescens* L.	24	Lal mirch
13.	Cinnamon (*Lauraceae*)	..	*Cinnamomum zeylanicum* Blume	24	Dalchini
14.	Clove (*Myrtaceae*)	..	*Syzygium aromaticum* L., *Eugenia aromatica* L., *E. caryophyllata* Thunb., or *Caryophyllus aromaticus* L.	..	Laung

1	2	3	4	5	6
15.	Coriander	..	See Leafy vegetables	..	..
16.	Cumin (*Umbelliferae*)	..	*Cuminum cyminum* L., or *C. odorum* S.	14	Jeera
17.	Curry leaf	..	See Leafy vegetables	..	..
18	Fennel (*Umbelliferae*)	.	*Foeniculum vulgare* Mill	22	Sonf, Shalpha
19	Fenugreek		See Leafy vegetables	..	..
20.	Garlic		See Bulb vegetables	..	..
21.	Ginger	..	See Underground veg.	..	..
22.	Hing (*Umbelliferae*)	.	*Ferula foetida* Regel.	22	Hing
23.	Indian mustard (*Cruciferae*)	..	*Brassica juncea* Coss.	36	Rai
24.	Mint or Peppermint (*Labiatae*)	..	*Mentha piperita* L.	36,64,66, 68,70,72	Podina
25.	Nutmeg (*Myristicacaae*)	..	*Myristica fragrans* Houtt., or *M. aromatica* Lam.	42	Jaiphal

1	2	3	4	5	6
26.	Omum (*Umbelliferae*)	..	*Trachyspermum ammi* L., or *Carum copticum* Benth	13	Ajwan
27.	Onion	O C.	See Bulb vegetables		
28.	Saffron (*Iridaceae*)	..	*Crocus sativus* L.	14,16, 24,40	
29.	Tamarind (*Leguminosae*)	..	*Tamarindus indica* L.	24	Imli
30.	Toria	.	See Leafy vegetables	..	..
31.	Turmeric (*Zingiberaceae*)	.	*Curcuma domestica* Val	32,62,64	Haldi
32.	White mustard	..	See Leafy vegetables		
		IX.	**Drugs, Dyes and Narcotics**		
1.	Blonde psyllium (*Plantaginaceae*)	..	*Plantago ovata* Forsk	8	Isbgol
2.	Camphor grass (*Gramineae*)	.	*Cymbopogon* [illegible]	[illegible]	

1	2	3	4	5	6
3.	Indigo (*Papilionaceae*)	O.C.	*Indigofera tinctoria* L.	16	Neel
4.	Indian hemp (*Cannabinaceae*)	C.	*Cannabis sativa* L.	30	Bhang
5.	Indian privet (*Lythraceae*)	..	*Lawsonia alba* Lam., or *Lawsonia inermis* L.	..	Mehndi, or Henna
6.	Lemon grass (*Gramineae*)		*Cymbopogon citrutus Stapf*	40,60	..
7.	Mango ginger (*Zingiberaceae*)	..	*Curcuma amâda*	42	Ama-haldi
8.	Opium poppy (*Papaveraceae*)	O.C.	*Papaver somniferum* L.	22	Post or Aphim
9.	Pyrethrum (*Compositae*)	..	*Chrysanthemum cinerarifolium* Vis.	18	Pyrethrum
10.	Safflower (*Compositae*)	..	*Carthamus tinctorius* L.	24	Kusum
11.	Tobacco (*Solanaceae*)	O.S.	*Nicotiana tabacum* L.	48	Tambaku

1	2	3	4	5	6
			X Plantation Crops		
1.	Betel nut (*Palmae*)	..	*Areca catechu* L.	32	Supari
2.	Cacao (*Sterculiaceae*)	.	*Theobroma cacao* L.	20	Koko kahva
3.	Camphor (*Lauraceae*)	..	*Cinnamomum camphora* Nees & Eberm. or *Camphora officinarum* Nees & Eberm	24	Kapur
4.	Cinchona (*Rubiaceae*)	..	*Cinchona officinalis* L.	34	.
5.	Coconut (*Palmae*)		*Cocos nucifera* L.	32	Nariyal
6.	Coffee (*Rubiaceae*)	S.	*Coffea arabica* L.	44	Coffee
7.	Para rubber (*Euphorbiaceae*)	.	*Hevea brasiliensis* M	36	Rubber
8.	Tea (*Theaceae*)	.	*Camellia thea* Link., or *C. sinensis* L.	30	Chay

1	2	3	4	5	6
			XI. Fruits		
1.	Almond (*Rosaceae*)	C	*Prunus amygdalus* Batsch, *Prunus communis* Arcang., or *Amygdalus communis* L.	16	Badam
2.	Apple (*Rosaceae*)	C.	*Malus sylvestris* Mill., *Malus communis* DC., or *Pyrus malus* L.	14	Seb, or Sev
3.	Apricot (*Rosaceae*)	S	*Prunus armeniaca* L., *P vulgaris* Lam	16	Khubani
4.	Atemoya (*Annonaceae*)	.	*Annona atemoya* Hort.	..	..
5.	Avocado (*Lauraceae*)	C	*Persea americana* Mill., or *Persea gratissima* Gaertn.	24	Avocado
6.	Bael fruit (*Rutaceae*)	.	*Aegle marmelos* Corr.	18	Bel
7	Banana (*Musaceae*)	C.	*Musa paradisiaca* L.	22,44	Kela
	(i) Dwarf banana	..	*Musa nana* Lour , or *Musa cavendishii* Lamb.	22,44	Chhota kela

1	2	3	4	5	6
	(ii) Plantain	..	*Musa sapientum* L.	12.44	Kachkela
8.	Bread fruit (*Moraceae*)		*Artocarpus altilis* Fosberg (*A. communis* Forst. or *A. incisa* L.)	54.76	Kathal or Khadal
9.	Bullocks heart (*Annonaceae*)	..	*Annona reticulata* L.	14	Ramphal
10.	Calamondin		See under Citrus fruits		..
11.	Cape gooseberry (*Solanaceae*)	..	*Physalis peruviana* L. or *P. edulis* Sims	[illegible]	Rasbhary
12.	Carambola (*Oxalidaceae*)	..	*Averrhoa carambola* L.	24	Kamrakh
13.	Caranda (*Apocynaceae*)		*Carissa carandas* L.	[illegible]	Karaunda
14.	Cashew-nut (*Anacardiaceae*)	..	*Anacardium occidentale* L.	42	Kaju
15.	Ceriman (*Araceae*)		*Monstera deliciosa* Liebm. or *M. lennea* Koch.	24.56	..

1	2	3	4	5	6
16.	Chalta (*Dilleniaceae*)	.	*Dillenia indica* L.	32	..
17.	Cherimoya (*Annonaceae*)		*Annona cherimolia* Mill.	14	Hanuman Phal
18.	Cherry (sour) (*Rosaceae*)	C	*Prunus cerasus* L.	32	Cherry
19.	Cherry (sweet) (*Rosaceae*)	C.	*Prunus avium* L.	16,32	Cherry
20	Chestnut, Sweet or Spanish (*Fagaceae*)	C	*Castanea sativa* Mill , or *Castanea vesca* Gaertn.	24	.
21.	Citrus fruits (*Rutaceae*)	S.	.		..
	(i) Calamondin	S.	*Citrus mitis* Blanco.	18	..
	(ii) Citron	S	*Citrus medica* L.	18	Turanj Gulgul
	(iii) Grape-fruit	S.	*Citrus paradisi* Macf.	18,36	..
	(iv) Kumquat (Round)	S.	*Citrus japonica* Thunb., or *Fortunella japonica* Swingle	18	..

1	2	3	4	5	6
	(v) Kumquat (oval)	S.	*Citrus margarita* Lour., or *Fortunella margarita* Swingle	18	.
	(vi) Lemon	S.	*Citrus limonia* Osbeck.	18	Khatti nimboo
	(vii) Lime	S.	*Citrus aurantifolia* Swingle	18,36	Kagzi nimboo
	(viii) Mandarin	S.	*Citrus reticulata* Blanco.	18	Santra
	(ix) Pumelo or Shaddock	S.	*Citrus maxima* Merr., or *C. documana* L.	18,36	Chakotra
	(x) Sour orange	S.	*Citrus aurantium* L.	18	Khatta
	(xi) Sweet orange	S.	*Citrus sinensis* Osbeck.	18,36	Malta, Mosambi
	(xii) Trifoliate orange	S.	*Citrus trifoliata* L. *Poncirus trifoliata* L., or *Aegle sepiaria* DC.	18,36	..
22.	Coconut (*Palmae*)	.	*Cocos nucifera* L.	32	Nariyal
23.	Crab apple (*Rosaceae*)	.	*Malus baccata* Borkh., or *Pyrus baccata* var. *sibirica* Maxim.	34	
24.	Custard apple, or Sweet sop (*Annonaceae*)	..	*Annona squamosa* L.	14	Sitafal, Sharifa

1	2	3	4	5	6
25.	Date (*Palmae*)	C.	*Phoenix dactylifera* L	36	Khajur
26.	Durian (*Bombacaceae*)		*Durio zibethinus* L.	..	
27.	Fig (*Moraceae*)	C	*Ficus carica* Murr.	26	Anjeer
28.	Governor's plum (*Flacourtiaceae*)	C	*Flacourtia indica* Merr., or *F. ramontchi* L' Herit.	22	
29.	..		*Flacourtia jangomas* R., or *F. cataphracta* Roxb.	..	Paniala
30	Grapes (*Vilidaceae*)	O S.	*Vitis vinifera* L.	38	Angur
31	Guava (*Myrtaceae*)		*Psidium guajava* L	22,33	Amrud, or Jamphal
32.	Hog plum (*Anacardiaceae*)		*Spondias pinnata* Kurz.	32	Amra
33.	Ilama (*Annonaceae*)	.	*Annona diversifolia* Safford.	..	

1	2	3	4	5	6
34.	Indian almond (*Combretaceae*)		*Terminalia catappa* L.	24	Desi Badam
35.	Indian gooseberry (*Euphorbiaceae*)	..	*Phyllanthus emblica* L.	28	Aonla
36.	Indian Jujube (*Rhamnaceae*)	C.	*Zizyphus jujuba* Mill.	24,40, 48,72,96	Ber
37.	Jack fruit (*Moraceae*)	C.	*Artocarpus integrifolia* L., or *A. heterophyllus* Lam.	18	Kathal
38.	Jalpai (*Elaeocarpaceae*)		*Elaeocarpus floribundus* Bl., or *E. seeratus* Linn.	..	..
39.	Jambolan, Rose apple (*Myrtaceae*)		*Syzygium cuminii* S., *Myrtus cuminii* L., or *Eugenia jambolana* Lam	44,66	Jamun
40.	Kokum (*Guttiferae*)	.	*Garcinia indica* Choisy	54	..
41.	Langsat (*Meliaceae*)	..	*Lansium domesticum* Jack	..	Lansa, Duku

1	2	3	4	5	6
42.	Longyen (*Sapindaceae*)	.	*Euphoria longan* Steud., *Dimocarpus longan* Lour., or *Nephelium longana* Camb	30	Laung
43.	Litchi (*Sapindaceae*)	C.	*Litchi chinensis* Sonn.	28,30	Lychee
44.	Loquat (*Rosaceae*)	C.	*Eriobotrya japonica* Lindl., or *Photinia japonica* Gray	34	Lokat
45	Mango (*Anacardiaceae*)	C	*Mangifera indica* L.	40	Am
46.	Mangosteen (*Guttiferae*)	.	*Garcinia mangostana* L.	76	Mangustan
47	Monkey Jack (*Moraceae*)		*Artocarpus lakoocha* Roxb.	56	Barhal, Daua
48.	Mulberry (*Moraceae*)	C.	*Morus alba* L.	28	Shahtut
49.	Muskmelon	C.	See Cucurbitaceous veg.	.	
50.	Natal plum (*Apocynaceae*)		*Carissa grandiflora* DC., or *Arduina grandiflora* E. May	.	..

1	2	3	4	5	6
51.	Olive (*Oleaceae*)	C.	*Olea europaea* L.	46	Zaitun
52.	Papaya (*Caricaceae*)	C.	*Carica papaya* L.	18,36	Papita
53.	Passion fruit (*Passifloraceae*)	.	*Passiflora edulis* Sims	18	..
54.	Peach (*Rosaceae*)	C.	*Prunus persica* Batsch, *P vulgaris* Lam., or *Amygdalus persica* L.	16	Aru
55.	Peach (European) (*Rosaceae*)	O S.	*Prunus domestica* L.	48	Alubhookhara
56.	Pear (*Rosaceae*)	C.	*Pyrus communis* L.	34,68	Nakh
57.	Pear (chinese or sand) (*Rosaceae*)	C	*Pyrus pyrifolia* var. *culta* N. *P serotina* var. *culta* Rehd., or *P. sinensis* Hort.	34	Naspati
58.	Pecan (*Juglandaceae*)	C.	*Carya pecan* E. & G. *C. illinoensis* Koch., or *Hicoria pecan* Britt.	..	..

1	2	3	4	5	6
59.	Persimmon (*Ebenaceae*)	.	*Diospyros virginiana* L.	60, 90	..
60.	Persimmon (Japanese) (*Ebenacede*)	..	*Diospyros kaki* L., or *D. chinensis* Blume.	90	..
61.	Phalsa (*Tiliaceae*)	..	*Grewia asiatica* L.	36	Phalsa
62.	Pine-apple (*Bromeliaceae*)	..	*Ananas comosus* Merr. *A. sativus* Schult., or *Bromelia comosa* L.	50,100	Ananas
63.	Pomegranate (*Punicaceae*)	O.C.	*Punica granatum* L.	16,18	Anar, Darim
64.	Quince (*Rosaceae*)	.	*Cydonia oblonga* Mill., *C. vulgaris* Pers., or *Pyrus cydonia* L.	34	Bihi
65.	Rambutan (*Sapindaceae*)	..	*Nephelium lappaceum* L.	..	..
66.	Rasp, Black or Dew berry, or Bramble (*Roaceae*)	C.	*Rubus idaeus* L.	14,28	Raspberry

1	2	3	4	5	6
75.	Walnut (Persian or English) (*Juglandaceae*)	C	*Juglans regia* L	32	Akhrot
76.	Wampee (*Rutaceae*)		*Clausena lansium* Skeels, or *Cookia wampi* Blanco	18	Ampeach
78.	Water chestnut (*Oenotheraceae*)	.	*Trapa bispinosa* *T. natans*	36	Singhara
79.	Watermelon (*Cucurbitaceae*)	C.	*Citrullus vulgaris* Schrad	22	Tarbuj
80.	Wood-apple (*Rutaceae*)	.	*Limonia acidissima* L , *Feronia limonia* L.	18	Kaitha

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